Strahlenschutzkommission

Geschäftsstelle der
Strahlenschutzkommission
Postfach 12 06 29
D-53048 Bonn

http://www.ssk.de

# Radiological protection during the decommissioning of the Asse II mine

Recommendation by the German Commission
on Radiological Protection

Adopted at the 283rd meeting of the German Commission on Radiological Protection on 15/16 September 2016

The German original of this English translation was published in 2016 by the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety under the title:

**Strahlenschutz bei der Stilllegung der Schachtanlage Asse**

Empfehlung der Strahlenschutzkommission

# Contents

## Preamble

Following a reassessment of the Asse II mine in 2008, the German Commission on Radiological Protection (Strahlenschutzkommission, SSK) has since been examining questions relating to radiological protection with a view to decommissioning the mine. As an advisory body to the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (Bundesministeriums für Umwelt, Naturschutz, Bau und Reaktorsicherheit, BMUB), one of the Commission's duties laid down in its statutes is to help ensure that the principles of radiological protection can be and are in fact complied with when decommissioning the Asse II mine in order to achieve the protection goals.

When reviewing past events in connection with emplacement of radioactive waste in the Asse II mine, public discussions have repeatedly led to accusations of scientists neglecting their duty to society and failing to share enough information about developments which, in hindsight, were deemed erroneous. The SSK therefore feels compelled to get involved and ensure that the principles of protection – justification, optimisation and application of dose limits – are taken into account, even under the difficult circumstances present at the Asse II mine. Within the context of an extremely complex undertaking such as the decommissioning of the Asse II mine, the SSK believes that humans and the environment can only be protected from the effects of ionising radiation if every factor involved is discussed openly and on an expert level.

## 1 Executive summary

In total, 124,494 containers of low-level radioactive waste and 1,239 containers of intermediate-level radioactive waste with a declared inventory of 7.8 PBq were emplaced in the Asse II mine between 1967 and 1978. In 2008, the Federal Government decided to decommission the mine in line with nuclear law. In doing so, it appointed the Federal Office for Radiation Protection (Bundesamt für Strahlenschutz, BfS) as the operator tasked with decommissioning the mine. In order to determine the best-possible decommissioning option, the BfS conducted a comparison of options (BfS 2010a). Four of the five assessment fields (safety during the operating phase, environmental effects in the event of an uncontrollable inflow of solution, feasibility and time requirements) indicated that there was a clear benefit to retaining the radioactive waste in the Asse II mine rather than retrieving it. Nevertheless, full retrieval was still stated as being the best decommissioning option because according to the BfS only the 'retrieval' option, including transport of the radioactive waste to a suitable repository, presented the justified expectation of being able to perform a long-term safety assessment, while such an assessment was not deemed safe to carry out for the 'complete backfilling' option. When comparing the three considered options, the 'relocation' option was accorded third place, not in the least due to a risk in terms of its legal feasibility. The results of the sensitivity analysis conducted as part of the comparison of options showed that the 'retrieval' option also exhibits significant uncertainties regarding the state of the radioactive waste and emplaced inventory, and these uncertainties have an impact on the option's feasibility. For this reason, fact-finding should be conducted to assess existing uncertainties in a systematic and comprehensive manner.

In 2013, the Atomic Energy Act (Atomgesetz, AtG 1985) was amended such that – among other things – retrieval of the radioactive waste from the Asse II mine was laid down by law (Lex Asse). This amendment was justified in the final Bundestag debate (Deutscher Bundestag 2013) by drawing upon the results of the comparison of options and the expectation that sufficient long-term safety cannot be proven if the radioactive waste is retained in the mine. According to the AtG, retrieval must be halted if the procedure represents an unjustifiable risk to the public and workers for radiological or other safety-related reasons. 'Lex Asse' is the 'Act

to Accelerate the Retrieval of Radioactive Waste and the Decommissioning of the Asse II Mine' and should be accomplished by waiving a planning approval procedure for retrieval and by simplifying the licencing procedure. Among other things, this means that – by way of derogation to § 117(16) in conjunction with § 50 of the German Radiation Protection Ordinance (Strahlenschutzverordnung, StrlSchV 2001) – the licencing authority can, where deemed necessary, stipulate the design basis accident planning value[1] at a value above the 50 mSv planning value for the effective dose provided in the StrlSchV.

During the legislative process, the continually declining state of the Asse II mine's rock and the risk that an uncontrollable inflow of solution could pose to the public were provided as reasons in favour of accelerating the procedure.

The SSK has been working with the Nuclear Waste Management Commission (Entsorgungskommission, ESK) since 2008 to examine questions pertaining to the decommissioning of the Asse II mine. As part of the present recommendation, the SSK investigates the radiological protection factors associated with decommissioning, provides an assessment of the current radiological protection factors, and offers recommendations largely aimed at boosting the level of protection for humans and the environment with a particular focus on supporting the implementation of national and international principles of radiological protection.

The SSK respects the decision taken by the legislature to retrieve the waste from the Asse II mine as quickly as possible. However, in line with its statutes, the Commission is obliged to provide an assessment of the associated radiological protection factors that is objective and, above all, independent of the institutions directly tasked with the decommissioning the mine. The Commission is also required to point out any potential or necessary measures for improvement.

By issuing this recommendation, the SSK underlines the importance of the principles of radiological protection – justification, optimisation and application of dose limits – that are anchored in national and international regulations. The SSK holds the view that these principles must also apply without limitation to the decommissioning of the Asse II mine. For this reason, it recommends that measures be taken to ensure these principles are given sufficient consideration during the course of all future decisions and measures. The SSK regrets that the legislative process to amend the AtG in 2013 (Lex Asse 2013) expressly excluded the application of the principles of justification and optimisation when considering to potentially halt retrieval, which in turn represents a major impediment to the principles of radiological protection as a whole. It would still be possible to perform optimisation within the retrieval process as a facet of practical radiological protection, but this would soon be likely to reach its limits because 'Lex Asse' would neither allow the full retrieval process to be halted, nor provide the option to amend the decommissioning process based on new findings or changes in circumstances, if the aim of performing full retrieval was affected by these measures. It would, in fact, be impossible to perform optimisation in line with the principles of radiological protection under such circumstances. Particularly when decommissioning the Asse II mine, the prevailing lack of knowledge renders optimisation crucial because an iterative process is the only way to ensure that the protection goals can be achieved to the best-possible extent. The SSK warns against diluting the level of protection accorded by national and international

[1] The design basis accident planning value describes the upper limit of the dose which must not be exceeded as a result of accidents in the mine or design basis accidents during planned activities (in this case: retrieval). An accident analysis is used to show that the dose potentially caused by the accidents to be observed does not exceed the design basis accident planning value.

radiological protection regulations. Beyond the present case, and with a view to protecting the public, such a dilution would make it impossible to foresee the hazards of nuclear emergencies. On top of that, such an approach collides with the provisions of Directive 2013/59/Euratom, e. g. Article 19(1).

The SSK notes that the process to decommission the mine is categorised as a planned exposure situation as per Directive 2013/59/Euratom (Euratom 2014) and the recommendations of the ICRP (ICRP 2007). As a result of this, exposures must be limited in line with the StrlSchV. The SSK holds the view that a transparent process should be used to stipulate the design basis accident planning value as soon as possible. It also believes that justification and stakeholder discussions are required if it is not possible to avoid exceeding the 50 mSv effective dose laid down in § 117(15) StrlSchV.

While assessing radiological protection factors, the SSK decided that when planning retrieval of the radioactive waste from the Asse II mine, it must also be assumed that at least part of the radioactive substances, such as the contaminated solutions deposited in the deep exposure and filling concrete made with non-clearable saline solutions, will be retained in the mine. There may also be no other alternative but to halt retrieval at any given point in the process to plan, prepare for and carry out retrieval. This could be due to the onset of conditions set out in the Act to Accelerate the Retrieval of Radioactive Waste and the Decommissioning of the Asse II Mine (Lex Asse 2013), or because of an uncontrollable inflow solution or other currently unforeseeable events or conditions. The SSK therefore recommends that ongoing stabilisation and precautionary measures, fact-finding and preparatory work to retrieve radioactive waste be accompanied by a corresponding analysis of consequences based on the latest advances in science and technology which can be also used to investigate and evaluate long-term safety if part of the radioactive waste is retained in the mine.

The SSK holds the view that the ‘retrieval’ and ‘complete backfilling’ options could constitute decommissioning variants which, given careful planning and execution, may be suited to achieving radiological protection goals. Provided a long-term safety assessment is required for the ‘complete backfilling’ option, the SSK considers the ‘complete backfilling’ option to have a clear advantage over the ‘retrieval’ option because the safe sealing of radioactive waste at its current place of storage would involve considerably lower doses to workers and far fewer risks from incidents and accidents than the recovery work which is currently expected to last several decades and in turn be followed by several decades of storage at a surface-level interim storage facility. The SSK has also taken more recent analyses as a basis for adopting the view that the waste does not pose a hazard to the public if it is retained in the mine.

The design basis accident planning value hitherto applicable in Germany, which ‘Lex Asse’ allows to be exceeded, was required because accidents are to be expected during the retrieval process, and the effective dose attributable to such accidents would exceed the limits laid down in the present StrlSchV. On the other hand, if the waste is retained in the mine, the SSK believes there is no need to be concerned about accidents that would lead to the present planning value for the effective dose being exceeded.

The full retrieval process and the potential retention of radioactive waste in the Asse II mine should both undergo analyses of consequences that are as comprehensive and realistic as possible since they are needed as a basis for performing process optimisation and long-term safety assessments.

The analysis of consequences for the ‘retrieval’ option must include the entire process, including the consequences of the anticipated long-term interim storage of retrieved radioactive waste.

The principle of optimisation plays a key role due to the prevailing lack of knowledge, e. g. regarding the state of the waste containers. Changes to the given circumstances and, above all, to the given level of knowledge are to be expected, particularly due to the extremely lengthy planning and implementation period spanning several decades. The SSK therefore recommends the optimisation measures be specified by way of an iterative process. The above-mentioned analyses of consequences form an important basis for optimisation as they allow for an assessment of the effects of changes made during the planning and implementation phase.

Potential doses should be determined as realistically as possible during planning as they form the basis for optimisation.

In order to be able to react appropriately to changes in conditions, e. g. if the mine is no longer deemed safe, the SSK recommends that analyses of consequences be performed along with a long-term safety assessment so that part of the waste can be retained in the mine. Despite current gaps in knowledge, the SSK expects such an assessment to be possible. In contrast to the situation presented by the BfS in 2010, which posited that there was not enough time available, the current schedule for the project as a whole does in fact provide enough time to carry out the analyses required for the long-term safety assessment.

The SSK has reviewed the radiological requirements in terms of long-term safety, and therefore recommends that long-term safety be assessed using the principle of application of dose limits, e. g. by using indicator values (target values), as is the case with the procedure at the Morsleben repository for radioactive waste (Endlager für radioaktive Abfälle Morsleben, ERAM) (SSK 2010). Indicator values of 0.1 mSv per year for probable developments and 1 mSv per year for less probable developments should be applied as criteria in order to evaluate potential public exposures over prolonged periods.

In order to obtain missing information and to reduce existing uncertainties, fact-finding work must be expedited for key parameters used in analyses of consequences, particularly for long-term assessments. The SSK recommends a systematic, iterative process be put in place to gather information.

The Commission considers it imperative to establish stakeholder analyses in order to involve relevant stakeholders in an open and transparent communication process.

Recommendations are presented and justified in Section 4.

# 2 Introduction

The SSK has been working with the ESK since 2008 to examine issues associated with decommissioning the Asse II mine. A joint ESK/SSK ad hoc ASSE working group was set up in July 2008. During such meetings, the SSK has regularly reviewed plans and measures to decommission the Asse II mine.

The SSK's deliberations on radiological protection questions came about as a result of advisory mandates from the Federal Ministry for the Environment, e. g. on emergency planning for the Asse II mine (ESK/SSK 2013), and as a result of information and findings gleaned while supporting and assessing the decommissioning plans.

The decommissioning of the Asse II mine revolves around questions on how to deal with the radioactive substances stored there, with a particular focus on the overarching aim of protecting humans from the hazards associated with such substances. In view of the latest advances in science and technology, it should be noted that the Asse II mine, in its current state, is neither suitable for the permanent storage of radioactive substances, nor does the emplacement method,

including transparency and documentation, comply with the current minimum technical requirements. This is compounded by the fact that the information and findings available to the SSK, e. g. regarding the state of the rock and waste containers, the hydrological conditions, and the conceivable release scenarios, are lacking, even by today's standards, and do not allow substantiated decisions to be taken. Fact-finding work to significantly improve upon this lack of knowledge has proven to be so time-consuming and complicated that the BfS has opted not to pursue it in the manner originally planned. The SSK therefore views these conditions as being unfavourable and therefore being like to hamper attempts to devise decommissioning solutions for the Asse II mine that are optimised in terms of radiological protection.

The SSK considers it its duty to help ensure that radiological protection objectives can be achieved. The principles of radiological protection are the focus of this recommendation. The need to protect humans and the environment from the effects of ionising radiation is based on the principles of justification, optimisation and application of dose limits which are anchored in national and international legislation and regulations. Given the prevailing conditions at the Asse II mine, the SSK holds the view that the radiological principle of optimisation plays a key role.

In this recommendation, the SSK investigates the radiological protection factors associated with decommissioning and provides an assessment of the current situation in light of said radiological protection factors. It also provides recommendations largely aimed at enhancing the protection of humans and the environment, with a particular focus on supporting the implementation of national and international principles of radiological protection.

These recommendations are based on open-source information.

# 3 Background and current situation

Potash salt and rock salt were mined at the Asse II mine between 1909 and 1964. After mining operations ended there, a total of 124,494 containers of low-level radioactive waste and 1,239 containers of intermediate-level radioactive waste with a declared inventory of 7.8 PBq were emplaced in the Asse II mine between 1967 and 1978. The Asse II mine was operated by the Gesellschaft für Strahlenforschung mbH (GSF)[2] on behalf of the Federal Government. Emplacement took place on the basis of the handling licences granted in line with the 1965 radiation protection ordinance applicable at that time, and in compliance with the applicable terms for storing radioactive waste at the Asse II mine. The radiological protection and nuclear emplacement licences were temporally limited and expired on 31 December 1978.

Since 1979, the mine has been kept open for research purposes while upholding and developing radiological monitoring, with the Gesellschaft für Strahlen- und Umweltforschung (GSF) appointed as the operator. In 1992, the Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung, BMBF) decided to terminate research work at the mine with the aim of decommissioning it. The GSF (now HGMU[2]) then carried out measures to stabilise the mine workings and devised a concept to close the mine (GSF 2006). The mine was supposed to be decommissioned in line with German mining law by 2016.

[2] This research centre has its headquarters in Neuherberg and has changed its name several times over the years: from 1964 to 1971 it was known as the Gesellschaft für Strahlenforschung (GSF), between 1971 and 1990 it was called the Gesellschaft für Strahlen- und Umweltforschung (GSF), between 1990 and 2008 it went by the name of GSF – Forschungszentrum für Umwelt und Gesundheit, and in 2008 it was given its current name: Helmholtz Zentrum München – Deutsches Forschungszentrum für Gesundheit und Umwelt (HMGU)

In 2008, until which time the facility had been operated according to mining law, the Federal Government decided to designate the mine a facility subject to nuclear law pursuant to Section 9a of the AtG (BMU 2008). The BfS was commissioned to take over the facility from the HMGU, previously GSF, and to operate and decommission the Asse II mine in line with the regulations incumbent upon repositories.

In 2009, the German Bundestag amended the AtG by adding Section 57b which governs the operation and decommissioning of the Asse II mine. It also stipulates that the facility must be decommissioned without delay, and that no plan approval procedure shall be required for ongoing operations until decommissioning has taken place.

A comparison of options performed by the BfS in 2009 provided a direct comparison and analysis of the decommissioning options for the Asse II mine (BfS 2010a). This comparison provided a range of potential options that differ as to the extent of the retrieved or relocated inventory, and in terms of their implementation method. Three options were assessed, namely

- full retrieval of the radioactive waste ('retrieval'),
- full relocation of the radioactive waste to a deep underground section of the Asse salt structure to be excavated ('relocation'), and
- backfilling ('complete backfilling') of the mine workings while retaining the radioactive waste at its current underground emplacement site ('complete backfilling').

As a result of this comparison, four out of the five assessment fields indicated significant benefits for the 'complete backfilling' option.

Based on the results of the comparisons within the assessment fields, a decision was to be taken between the 'retrieval' and 'complete backfilling' options. The BfS preferred the 'retrieval' option as it was unsure whether a long-term safety assessment could be performed for the 'complete backfilling' option. According to the BfS, the investigations needed to clarify the given uncertainties regarding a long-term safety assessment for complete backfilling could not be performed while preparing the comparison of options due to a lack of time (BfS 2010a). In doing so, the BfS amended the statement it made in 2007 as part of its assessment of the documentation submitted by the GSF regarding a decommissioning concept involving complete backfilling. In 2007, the BfS stated that if the decommissioning measures were implemented as required, the present long-term safety assessment would '*indicate plausibly that the protection objectives have been met*', although this statement only applies to radionuclide releases via the gas pathway (BfS 2007).

In 2010, the Federal Ministry for the Environment had not arrived at a final decision based on the comparison of options because the results of the fact-finding process were also to be used to arrive at a final decision.

In April 2010, the BfS submitted a concept (DMT and TÜV Nord 2010) relating to the fact-finding process included in the comparison of options. Fact-finding should serve to provide information about the state of the emplacement mine workings and the radioactive waste stored there. This information is essential in order to be able to assess the feasibility of retrieval, review its justification, and subsequently decide on and plan retrieval (BfS 2011).

On 28 February 2013, the German Bundestag passed another amendment to the AtG, known as 'Lex Asse', with the aim of accelerating the retrieval of radioactive waste and the decommissioning of the Asse II mine (Lex Asse 2013). The Bundesrat adopted the act on 5 July 2013. It prescribes the immediate decommissioning of the mine following retrieval of the radioactive waste currently stored there. Among other things, it also governs exemption levels for the handling of radioactive substances not requiring a licence, and calls for stipulation of

design basis accident planning values on a case-by-case basis. The law also governs the terms under which retrieval is to be halted.

In February 2014, the BfS published its first-ever general retrieval plan based on the situation as of January 2014 (BfS 2014).

On 15 April 2015, the BfS published a report to the effect that key steps of the fact-finding process should be left out due to time constraints (BfS 2015).

The plans were made and decisions were taken based on the notion that the rock's state is constantly deteriorating, that there is a risk of an uncontrollable inflow of solution, and against the backdrop of controversial discussions among local residents near the mine which currently involve the site of the interim storage facility. In addition, the last seven years have been defined by drastic changes to the schedule, including the assumed length of time to perform fact-finding which has risen from three to almost 20 years (Arcadis 2013).

# 4 Assessment and recommendations

## 4.1 The radiological consequences of an uncontrollable inflow of solution

After assuming responsibility for operating and decommissioning the Asse II mine, the BfS investigated whether a hazard to local residents near the facility can be assumed until decommissioning has been completed, i.e. until the radioactive substances present in the radioactive waste emplaced in the mine have been stored safely. The BfS assessment showed that there could be a hazard resulting from an uncontrollable inflow of solution. In the event of such an uncontrollable inflow of solution, the likes of which have already been seen in similar mines in the past, it is assumed that all or part of the radioactive substances present in the waste will be released into the solution and, over a period spanning at least several decades, this solution will be pressed out of the mine and reach sources of drinking water or other water used by humans.

According to nuclear law, an uncontrollable inflow of solution is a beyond-design-basis event, while mining law designates it an emergency.

Back in 2009, the BfS commissioned two studies to estimate potential exposures as a result of an uncontrollable inflow of solution at the Asse II mine (GRS 2009, AF-Colenco AG 2009)[3]. The Oeko-Institut later commissioned an additional study on behalf of the Federal Ministry for the Environment to assess the relevance of influencing factors (Oeko-Institut 2012)[4]. All of the studies were based on the assumption that the shafts can be sealed before abandoning the mine in such a way that there will be no significant solution outflow.

The results of the studies indicate a broad range of values in keeping with their underlying conditions. Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH used rough, overly conservative and, at times, unrealistic assumptions as a basis for calculating potential effective annual doses of approx. 170 mSv for an adult reference person and approx. 740 mSv for an infant reference person up to the age of one year that would apply in a 'basic case' for the 40th

[3] An additional study on the consequences of precautionary and emergency measures (GRS 2010) is also available that contains estimates of radionuclide emissions from the mine to the overburden. However, the study does not provide any potential dose calculations.

[4] For the sake of completeness, (Krupp 2009) provides a hydrogeological model describing how saline solutions are squeezed out of the Asse II mine after an uncontrollable inflow of solution. No statements were provided in terms of radionuclide concentrations in groundwater close to the surface, nor regarding public exposure.

year after the onset of inflow of solution. It should be pointed out, however, that the authors of the study intended these values to be taken as estimates. AF-Colenco also used overly conservative and, in part, unrealistic assumptions as a basis for calculating the maximum potential doses with a 10 mSv effective annual dose for an adult reference person within the general public. According to these calculations, this dose will be reached approx. 50 to 100 years after the mine has been flooded. Taking account of sorption and the solubility limits for various types of squeezing-out rates, the Oeko-Institut models resulted in effective doses of 0.02 mSv per year to 0.04 mSv per year for the adult reference person, and 0.04 mSv per year to 0.1 mSv per year for the infant reference person up to the age of one year.

The SSK considers that the estimates for the radiological effects of an uncontrollable inflow of solution in (AF-Colenco AG 2009) and (GRS 2009) provide extremely unfavourable and unrealistic results as they are based on highly simplified models with overly conservative and unrealistic assumptions that fail to take account of retention effects due to physical and chemical interactions. Such interactions are naturally occurring effects and conditions, meaning that they must be considered in order to arrive at a hazard assessment that is as realistic as possible.

Both estimates assume, for example, that after an uncontrollable inflow of solution, the radionuclides present in the waste will fully dissolve in the inflow water and then be squeezed out into the hydrosphere and biosphere as a result of convergence and gas formation in the mine. However, the estimates fail to take into account the solubility limits in the saline solution and drinking water, both of which have a significant effect on the result, and also omit the sorption effects that occur when passing through the overburden. They also fail to consider the fact that only a very small proportion of the uranium and thorium is soluble; otherwise the solubility limit of uranium and thorium would be exceeded in the saline solution.

For this reason, the SSK affirms the assessment by the ESK/SSK ad hoc working group ASSE (ESK/SSK ad hoc working group ASSE 2009) which states that the studies from 2009 are insufficient in terms of providing a realistic assessment of the hazard associated with an uncontrollable inflow of solution.

The Oeko-Institut models, on the other hand, take sorption and solubility limits into account in their estimates of the radiological consequences of an uncontrollable inflow of solution, thus representing an important step towards a realistic assessment of potential public exposures. These models should be gradually continued by way of more complex models that map the conditions at the Asse site in more detail. This also requires more accurate exploration of the hydrogeological conditions at the Asse II mine, as already recommended by the ESK and SSK (ESK/SSK 2008).

In order to determine consequences and measures, ICRP Publication 103 calls for realistic calculations in the form of ‘best estimates’ that quantify uncertainties for an existing exposure situation, as would be the case in the event of uncontrolled flooding of the Asse II mine. The identification of practices for which an assessment of doses needs to be carried out in a realistic way is also a requirement incumbent upon EU Member States as stipulated in Article 66(2) of Directive 2013/59/Euratom. The SSK recommended principles for a realistic dose assessment (SSK 2013) in which it recommended the realistic assessment of doses for long-term assessments of repositories.

The Oeko-Institut also pointed out this problem in connection with modelling the radionuclide transfer via the foodstuff pathway when using contaminated water. For this reason, the Oeko-Institut performed calculations based on both the general administrative regulation for § 47 of the StrlSchV (BMU 2012) and the Calculation Guide Mining (BfS 2010c). The SSK holds the view that the Calculation Guide Mining approximately meets the realistic methods requirements set out in Directive 2013/59/Euratom (Euratom 2014) and the basic

recommendations of ICRP Publication 103. The models based on the Calculation Guide Mining led to effective doses that were 2 to 6 times lower than those calculated on the basis of the general administrative regulation for § 47 of the StrlSchV.

The Oeko-Institut (Oeko-Institut 2012) results permit the expectation that the radiological consequences of an uncontrollable inflow of solution are much lower than the design basis accident planning value applicable to design basis accidents (max. 50 mSv up to the age of 70) and will not reach the intervention levels for emergency measures (e. g. 100 mSv in 7 days for evacuation). As a result, the SSK holds the view that an uncontrollable inflow of solution does not represent a hazard[5] to the public.

## 4.2 Decommissioning options

In order to determine the best-possible decommissioning option, the BfS performed a comparison of options. Four of the five assessment fields (safety during the operating phase, environmental effects in the event of an uncontrollable inflow of solution, feasibility and time requirements) indicated that there was a clear benefit to retaining the radioactive waste in the Asse II mine rather than retrieving it. However, full retrieval was still seen as being the best decommissioning option because the BfS holds the view that only the 'retrieval' option, including transport of the radioactive waste to a suitable repository, presents the justified expectation of being able to perform a long-term safety assessment, while such an assessment for the 'complete backfilling' option is not deemed safe to carry out. When comparing the three considered options, the 'relocation' option was accorded third place, not in the least due to a risk in terms of its legal feasibility. The results of the sensitivity analysis conducted as part of the comparison of options showed that the 'retrieval' option also exhibits significant uncertainties regarding the state of the radioactive waste and emplaced inventory, and these uncertainties have an impact on the option's feasibility. For this reason, fact-finding should be conducted to provide various opportunities to assess critical uncertainties in a systematic manner.

From a radiological protection perspective, the SSK posits that the 'retrieval' and 'complete backfilling' options constitute decommissioning variants which, given careful planning and execution, may be suited to achieving radiation protection goals. There is currently so little knowledge available for the 'relocation' option that it is not possible to provide any statements about the feasibility of a suitable emplacement zone with regard to long-term safety factors. This is compounded by the fact that the comparison of options generally rates relocation less favourably compared to retrieval and complete backfilling.

However, the SSK does not view the execution and consequences of full retrieval as optimistically as it is portrayed in the comparison of options. Provided the long-term safety assessment is to be carried out for the 'complete backfilling' option, the SSK considers the 'complete backfilling' option to have a clear advantage over the 'retrieval' option because the safe sealing of radioactive waste at its current place of storage would involve considerable lower doses and far fewer risks from incidents and accidents than the recovery work which is currently expected to last several decades and in turn be followed by several decades of storage at a surface-level interim storage facility. On top of that, the SSK holds that the hazard an uncontrollable inflow of solution poses to the public based on previous conservative and unrealistic analyses can apparently be excluded in view of more recent analyses. In the event of controlled complete backfilling, e. g. using protective fluid and structures to reduce

[5] A hazard is only present if emergency radiological protection measures are required. Risks from lower radiation doses that do not represent a hazard will be considered separately.

dissolution of the waste and dispersion of the radionuclides, the SSK takes the view that potential doses can be assumed to be far lower.

The design basis accident planning value applicable hitherto in Germany, which 'Lex Asse' allows to be exceeded, was required because accidents (e. g. a container falling in the shaft (EWN and TÜV Nord 2008)) are to be expected during the retrieval process, and the effective dose attributable to such accidents would exceed the design basis accident planning value permitted in the StrlSchV). The SSK posits that controlled complete backfilling does not give rise to concerns about radiologically relevant accidents.

The comparison of options is based on the feasibility study for retrieval of low active waste (DMT and TÜV Nord 2009), which in turn is based on optimistic assumptions, e. g. that the retrieval of radioactive waste could largely take place by way of existing galleries and, in particular, shaft two without the need for any major changes to the ventilation network. At that time, a period of 10 years was estimated for full retrieval, including planning and procedural work to be performed in advance.

Since then, findings have been gleaned to put the former retrieval assessment into perspective. The poor state of the mine workings in terms of stability and ventilation techniques does not permit retrieval of the radioactive waste using the existing mine workings, meaning that a new shaft, new galleries and new chambers will need to be excavated.

According to the current state of planning, the retrieval process and its accompanying preparatory work could take several decades to complete. The current plan is to commence retrieval in 2033 and complete the procedure in 2046 (Arcadis 2013), i.e. 36 years after initiation of the plans started as a result of the comparison of options. Only then can the mine actually be decommissioned, a process requiring an additional 4 to 5 years based on the comparison of options.

The time delay compared to the assumptions in the comparison of options bears several disadvantages: the shaft would have to be kept open for much longer, thus increasing exposures to workers and the public, there would be a higher risk of mining accidents and uncontrollable inflow of solution, while the amount of effort and resources involved would also rise to match. Based on experiences gleaned from other large-scale projects, it can be assumed that the amount of time required for planning and execution is likely to increase rather than decrease.

It is already clear at this time that radioactive substances, such as the contaminated solutions deposited in the deep exposure and filling concrete made with non-clearable saline solutions, will be retained in the mine. Retrieval may also be halted at any given point in the process to plan, prepare for and carry out retrieval. This could be due to the onset of conditions (see Section 4.3.3) set out in 'Lex Asse' (Lex Asse 2013), or because of an uncontrollable inflow of solution or other currently unforeseeable events or conditions.

For these reasons, the SSK does not consider full retrieval to have been proven feasible, and the prevailing lack of knowledge renders it impossible to obtain and furnish such proof. The SSK therefore considers it necessary to take the retention of waste in the mine into account during the planning phase and to at least perform analyses of consequences, including the question of long-term safety for both of the above variants, in order to preclude avoidable delays during subsequent stages of the project and to be sufficiently prepared to halt retrieval of the radioactive waste from the Asse II mine and complete retrieval in the requisite scope on schedule.

The comparison of options states that delays of nine years are to be expected when performing complete backfilling. However, this option is far less complex than retrieval, meaning that

complete backfilling delays cannot be expected to increase to the same extent as retrieval delays.

Given the prevailing lack of facts, the SSK holds the view that it is not possible to definitively determine which of the potential approaches would be in the best interests of radiological protection, i.e. which of the variants would be feasible at the current stage in the planning process. In view of the purported state of the waste containers, the extremely long preparation period in the future, and the inevitable associated deterioration in circumstances surrounding the state of the emplacement chambers and containers, the SSK believes that 'retrieval' cannot be expected to be implemented in full. In addition, incidents and accidents or other conditions that may lead to retrieval being halted must be included in the planning process. The 'Lex Asse' already governs how to proceed in such cases. The planning scope should be extended to avoid impediments to radiological protection due to unplanned incidents and circumstances.

## 4.3 Principles of radiological protection

This recommendation covers radiological protection questions in connection with the retrieval of radioactive waste, the operation and decommissioning of the Asse II mine, the long-term safety of radioactive substances retained in the mine, and retrieved radioactive waste. It is based on the corresponding amendments to the AtG from 2008 and 2013, current legislation pertaining to radiological protection as well as future requirements imposed by the new Directive 2013/59/Euratom (Euratom 2014), and the pertinent recommendations from the ICRP (ICRP 2007, ICRP 2013) and the IAEA (IAEA 2011).

### 4.3.1 Principles of radiological protection (national and international)

The three **principles of radiological protection** are justification, optimisation, and application of dose limits. These principles, which have been recommended and applied for decades, were confirmed by the ICRP in its basic recommendation in ICRP Publication 103 (ICRP 2007). The principles of justification and optimisation are of particular relevance to this recommendation.

According to (ICRP 2007) , **justification** is "*The process of determining whether either (1) a planned activity involving radiation is, overall, beneficial, i.e. whether the benefits to individuals and to society from introducing or continuing the activity outweigh the harm (including radiation detriment) resulting from the activity; or (2) a proposed remedial action in an emergency or existing exposure situation is likely, overall, to be beneficial, i.e., whether the benefits to individuals and to society (including the reduction in radiation detriment) from introducing or continuing the remedial action outweigh its cost and any harm or damage it causes*."

According to (ICRP 2007), **optimisation** is "*The process of determining what level of protection and safety makes exposures, and the probability and magnitude of potential exposures, as low as reasonably achievable, economic and societal factors being taken into account*."

In (ICRP 2007), the ICRP provides three different **exposure situations** that are also relevant to questions pertaining to the Asse II mine. These situations are known as planned exposure situations, emergency exposure situations and existing exposure situations:

- **Planned exposure situations**: A situation that arises from the planned operation of a source, including decommissioning, disposal or radioactive waste, and remediation of previously polluted areas. Ongoing activities are planned exposure situations.
- **Emergency exposure situations**: A non-routine situation that occurs or may occur during the operation of a practice or work activity and that necessitates prompt action primarily

to mitigate a hazard or adverse consequences for human health and safety, quality of life, property or the environment. This includes situations for which prompt action is warranted to mitigate the effects of a perceived hazard.

– **Existing exposure situations**: A situation that already exists when a decision on control has to be taken, including natural background radiation and residues from past practices that were operated outside the Commission's recommendations. Many types of existing exposure situations can lead to doses that are high enough to justify performing or at least considering radiation protection measures.

The ICRP sees the need for justification and optimisation when it comes to planned exposure situations, which is why it recommends the application of dose limits and dose constraints[6] for workers and the public.

All of the decommissioning work performed at the Asse II mine should be considered planned exposure situations.

The ICRP emphasises the importance of optimisation to be performed for planned exposure situations below the dose constraints.

As a result of the amendment to the German Atomic Energy Act (AtG) in 2009, the Asse II mine is to be decommissioned in line with regulations incumbent upon repositories. Beyond the scope of German nuclear law, ICRP Publication 122 (ICRP 2013) and IAEA Basic Safety Standard SSR-5 (IAEA 2011) also apply to the radiological protection safety requirements placed on the final disposal of radioactive waste.

German radiological protection regulations currently lack legislation covering the requirements placed on the final disposal of radioactive waste in deep geological formations. The Safety Criteria for the Final Disposal of Radioactive Waste in Mines produced by the Federal Ministry of the Interior in 1983 (Federal Ministry of the Interior, BMI 1983) no longer apply and have been replaced by the Safety Requirements Governing the Final Disposal of Heat-generating Radioactive Waste of 30 September 2010 (BMU 2010) from the Federal Ministry for the Environment which apply to repositories to be built for storing heat-generating radioactive waste. No new regulations or legislation have been introduced for non-heat-generating radioactive waste since that time.

The Morsleben repository is currently being decommissioned on the basis of these criteria, although the 0.3 mSv per year limit (BMI 1983) has been replaced by an indicator value of 0.1 mSv per year for probable developments and 1 mSv per year for less probable developments, cf. (SSK 2010). These criteria are in line with ICRP Publication 122 (ICRP 2013), which contains the following:

– *"For the protection of the future generations, the Commission recommendations continue to rely on the basic principle that: 'individuals and populations in the future should be afforded at least the same level of protection as the current generation' (ICRP, 1998).*

– *The Commission views the potential exposures to humans and the environment associated with the expected evolution of the geological disposal of long-lived solid radioactive material as a planned exposure.*

[6] Dose constraints are not limits. They are used to define the range of options considered in the process of optimisation for a given radiation source in a planned exposure situation (Euratom 2014).

- *If oversight ceases to exist in the post closure period, the disposal system is still a functioning facility and potential exposures should be considered as planned.*
- *Optimisation of protection is the central element of the stepwise design, construction, and operation of a geological disposal facility.*
- *Optimisation has to be understood in the broadest sense as an iterative, systematic, and transparent evaluation of protective option, including Best Available Techniques, for enhancing the protective capabilities of the system and reducing its potential impacts (radiological and others).*
- *In application of the optimisation principle, the radiological criterion for the design of a waste disposal facility recommended by ICRP is an annual dose constraint for the population of 0.3 mSv year$^{-1}$ and below the annual dose limit of 20 mSv year$^{-1}$ or 100 mSv in 5 years for occupationally exposed workers.*
- *A risk constraint for the population of 1 $\times$ 10$^{-5}$ year$^{-1}$ is recommended when applying an aggregated approach combining probability of the exposure scenario and the associated dose.*
- *In the very long term, dose and risk criteria should be used for the comparison of options rather than a means of assessing health detriment.*
- *For planned exposure situations, doses should be assessed on the basis of the annual dose to the representative person."*

The IAEA Safety Requirements for the final disposal of radioactive waste (IAEA 2011) also specify criteria whose acceptable risks are in line with those of the ICRP.

"*Criteria*

*(a) The dose limit for members of the public for doses from all planned exposure situations is an effective dose of 1 mSv in a year [3]. This and its risk equivalent are considered criteria that are not to be exceeded in the future.*

*(b) To comply with this dose limit, a disposal facility (considered as a single source) is so designed that the calculated dose or risk to the representative person who might be exposed in the future as a result of possible natural processes affecting the disposal facility does not exceed a dose constraint of 0.3 mSv in a year or a risk constraint of the order of 10$^{-5}$ per year.*"

### 4.3.2 Legal basis

§§ 4 to 6 StrlSchV govern and describe the principles of justification, optimisation and application of dose limits.

§ 4 StrlSchV defines **justification** as follows: *"New kinds of practices which would be subject to § 2, para. (1), subpara. 1 and which may entail radiation exposure or contamination of man and environment must be justified by their economic, social or other benefits in relation to the health detriment they may cause. Existing types of practices may be reviewed as to justification whenever new and important evidence about their efficacy and consequences is acquired."*

§ 6 StrlSchV covers the principle of **optimisation** by demanding the 'avoidance of unnecessary radiation exposure' and 'dose reduction':

*"(1) Anyone who plans or performs a practice pursuant to § 2, para. (1), subpara. 1 shall avoid any unnecessary radiation exposure or contamination of man and environment.*

*(2) Anyone who plans or performs a practice pursuant to § 2, para. (1), subpara. 1 shall minimise any unnecessary radiation exposure or contamination of man and environment, even*

*if below the respective limit, by taking into consideration the state of the art and by taking into account all circumstances of individual cases."*

The principle of **application of dose limits** is covered by § 5 StrlSchV which stipulates a limitation of doses for workers and the general public.

Radiological protection legislation is scheduled for a major revision as Directive 2013/59/EURATOM (Euratom 2014) was passed in 2013 and must be adopted into national law within four years. The new Directive 2013/59/Euratom confirms the existing radiological protection system and amends the basic standards placed on the various exposure situations pursuant to ICRP Publication 103 (ICRP 2007) along with the associated system of reference levels, limits and dose constraints. In particular, the three principles of radiological protection – justification, optimisation and application of dose limits – remain applicable to all exposure situations, while the system of limits and dose constraints continues to apply to planned exposure situations.

Article 19, 'Justification of practices', of Directive 2013/59/Euratom includes, in particular, the following description of **justification**:

*"(1) Member States shall ensure that new classes or types of practices resulting in exposure to ionising radiation are justified before being adopted.*

*(2) Member States shall consider a review of existing classes or types of practices with regard to their justification whenever there is new and important evidence about their efficacy or potential consequences or new and important information about other techniques and technologies.*

*(3) Practices involving occupational and public exposures shall be justified as a class or type of practice, taking into account both categories of exposures."*

According to Article 28 of Directive 2013/59/Euratom, "*the operation, decommissioning and closure of any facility for the long-term storage or disposal of radioactive waste, including facilities managing radioactive waste for this purpose*" represent a planned exposure situation subject to licensing and for which limits and dose constraints therefore apply. The limits and dose constraints provided in Directive 2013/59/Euratom correspond with those set out in ICRP 103 (ICRP 2007).

### 4.3.3 Act to Accelerate the Retrieval of Radioactive Waste and the Decommissioning of the Asse II Mine ('Lex Asse')

In 2009, the German Bundestag amended the AtG by adding Section 57b which governs the operation and decommissioning of the Asse II mine. It also stipulates that the facility must be decommissioned without delay, and that no plan approval procedure shall be required for ongoing operations until decommissioning has taken place. On 28 February 2013, the German Bundestag passed a law known as 'Lex Asse' with the aim of accelerating the retrieval of radioactive waste and the decommissioning of the Asse II mine (Lex Asse 2013). The Bundesrat adopted the act on 5 July 2013. It prescribes the immediate decommissioning of the mine following retrieval of the radioactive waste currently stored there. Among other things, it also governs exemption levels for the handling of radioactive substances not requiring a licence, and calls for stipulation of design basis accident planning values on a case-by-case basis.

At the German Bundestag debate held on 28 February 2013, the lack of a long-term safety assessment in the event of retaining the radioactive waste in the mine was stated as being the main reason for deciding in favour of retrieval: *"There is no long-term safety assessment available for retention of the waste in the mine. Statements provided by the Federal Office for Radiation Protection (BfS) indicate that this is also unlikely to happen in the future. As a result*

*of that, retrieval is the only option available to end the dangerous and illegal situation at the Asse II mine."* (Deutscher Bundestag 2013, page 27999); *"...it was not until 2009, once the Federal Office for Radiation Protection (BfS) had performed a comparison of options, that it became absolutely clear that a long-term safety assessment cannot be performed if the waste remains in the mine.*" (Deutscher Bundestag 2013, page 28001)

The following measures have been agreed on in order to accelerate the retrieval process:

- Retrieval of the radioactive waste shall not require a planning approval procedure, but a nuclear or radiological protection licence.
- The licencing authority may allow preparatory retrieval measures subject to approval to start before a licence has been issued.
- Partial licences may be issued.
- If, as well as the nuclear or radiological protection licence, an approval based on other legislation is required, the licence will also include this approval.
- Handling radioactive substances underground does not require a licence if the activity of the substances is not more than ten times the exemption values set out in column 3 of table 1 of Annex III StrlSchV.
- By way of derogation to the StrlSchV, the licencing authority may permit a design basis accident planning value in excess of 50 mSv for the effective dose. The design basis accident planning value is a value that quantifies public exposure in the event German Bundestag of an accident attributable to retrieval planning.

The German Bundestag debate stated the continually declining state of the Asse II mine's rock and the risk that an uncontrollable inflow of solution could pose to the public as the reasons for the need for acceleration.

The law also governs the terms under which retrieval is to be halted. Retrieval must be halted if the procedure represents an unjustifiable risk to the public and workers for radiological or other safety-related reasons. According to 'Lex Asse', this is particularly the case if the dose limits for the public (incl. 1 mSv per year for the effective dose) and for occupationally exposed persons (incl. 20 mSv per year for the effective dose) cannot be complied with or if the safety of the mine can no longer be ensured.

Given the intention of the legislator, the principles of justification and dose minimisation do not constitute grounds for halting retrieval.

If retrieval of the waste and all options to decommission the mine are only achievable by deviating from statutory requirements, the Asse II mine should be decommissioned by opting for the best-possible option following due consideration of the advantages and disadvantages. The German Bundestag must be informed prior to taking such a decision and, provided there is no need for immediate action, the public must be given an opportunity to respond.

As a result of the further legislative process, the principles of radiological protection were narrowed down to the application of dose limits. During the German Bundestag debate on 28 February 2013, this amendment was described as follows: *"After the 'Lex Asse' hearing we introduced some changes. [...] Above all, we have agreed to state the principles of radiological protection as potential criteria for halting the process. Only the dose limit is now stated as an example of a criterion. This draft act is designed to explicitly express that justification for retrieval and the minimisation requirement* [...] *will not constitute criteria for halting the process.* [...] *We want to express* [...] *that justification for retrieval cannot be reconciled with*

*the aim of establishing retrieval as the preferred option*." (Deutscher Bundestag 2013, page 28001).

Given the prevailing lack of facts, it is not possible to take a final decision in terms of which option or combination of options is to be used to decommission the mine. In spite of the pending investigations and assessments, and despite the given associated uncertainties, the legislature's amendment of the AtG in 2013 constitutes a decision in favour of the full retrieval option. As already described in Section 4.2, the SSK believes that 'retrieval' cannot be expected to be implemented in full due to the purported state of the waste containers, the extremely long preparation period in the future, and the inevitable associated deterioration in circumstances surrounding the state of the emplacement chambers and containers. In addition, incidents and accidents or other conditions that may lead to retrieval being halted must be included in the planning process.

Radiological protection requirements are formulated and anchored in national and international legislation and regulations in the form of the radiation protection principles justification, optimisation and dose limits. The parliamentary process refrained from referring to the principles of radiological protection, instead only referring to the principle of application of dose limits (§ 5 StrlSchV). The principle of optimisation, i.e. the avoidance of any unnecessary radiation exposure or contamination of humans and the environment (§ 6 StrlSchV), is not covered by the Act.

The SSK regrets that the legislative process to amend the AtG in 2013 (Lex Asse 2013) explicitly excluded the observance of the principles of justification and optimisation with a view to potentially halting retrieval (Deutscher Bundestag 2013), which in turn represents a major impediment to the application of the principles of radiological protection as a whole. It would still be possible to perform optimisation within the retrieval process as a facet of practical radiological protection, but this would soon be likely to reach its limits because 'Lex Asse' neither allows the full retrieval process to be halted, nor does it provide the option to amend the decommissioning process based on new findings or changes in circumstances, even if they were to align with the aim of performing full retrieval. It would in fact be impossible to perform optimisation in line with the principles of radiological protection under such circumstances. Particularly when decommissioning the Asse II mine, the prevailing lack of knowledge renders optimisation crucial because an iterative process is the only way to ensure that the protection goals can be achieved to the best-possible extent. The SSK warns against diluting the level of protection accorded by national and international radiological protection regulations. Beyond the present case, and with a view to protecting the public, such a dilution would make it impossible to foresee the hazards of nuclear emergencies. In addition, such an approach collides with the stipulations of Directive 2013/59/Euratom, e. g. Article 19(1).

From a legal perspective, the view held by the BfS and the BMUB, which has been conveyed to the SSK, is that the amendment to the AtG already provides justification for the option to perform retrieval. The SSK does not see itself in a position to assess this legal issue. However, the SSK considers it unacceptable for a law to practically abrogate the basis of national and international radiological protection by expressly eschewing optimisation of the protection of humans and the environment.

The SSK believes that the principle of optimisation is indispensable, and this also applies to the retrieval of radioactive waste and the decommissioning of the Asse II mine.

The SSK also considers it a major step backwards in terms of radiological protection for workers and the public if only the principle of application of dose limits is taken into account.

### 4.3.4 Basic requirements placed on compliance with the principles of radiological protection

As already described and reasoned above, the SSK believes that the principles of radiological protection laid down in national and international regulations cannot be dispensed with, and this also applies to the decommissioning of the Asse II mine. The SSK recommends the introduction of regulations to ensure that the principles of radiological protection are given due consideration within the scope of all future measures and decisions taken in connection with and during decommissioning of the Asse II mine.

**Recommendation 1: Principles of radiological protection**

**The SSK recommends ensuring that the three principles of radiological protection – justification, optimisation and application of dose limits – can and are in fact given due consideration within the scope of all future measures and decisions taken in connection with decommissioning the Asse II mine.**

### 4.3.5 Dose limits

According to ICRP Publication 103 (ICRP 2007) and Council Directive 2013/59/Euratom, the principle of application of dose limits for workers and individual members of the public is implemented using a system of limits to be applied in planned exposure situations as well as reference levels to be used in existing or emergency exposure situations. § 5 StrlSchV governs the limitation of doses for planned exposure situations by stipulating dose limits.

After decommissioning, the SSK suggests adopting the indicator values stipulated for the Morsleben repository (see Section 4.4).

This provides a system of limits and indicator values for public radiological protection which the SSK considers to be a sound basis for radiological protection design when it comes to retrieving the radioactive waste from and decommissioning the Asse II mine. This complies with (ICRP 2007, ICRP 2013, IAEA 2011, Euratom 2014 and SSK 2008):

- For practices undertaken during the course of retrieval, interim storage, conditioning and decommissioning, which are categorised as planned exposure situations, there is an effective dose limit of 1 mSv per year for the public (provided everything goes to plan). Dose limits also apply as a result of discharges via the air pathway and water pathway. German law sets this limit for each pathway at 0.3 mSv per year for the effective dose, with both limits applicable for reasonable periods of time.
- For prolonged periods of time, an indicator value of 0.1 mSv per year for probable developments and 1 mSv per year for less probable developments is to be applied for the effective dose in accordance with a "*risk constraint for the population of* $1 \times 10^{-5}\ a^{-1}$" as per (ICRP 2013).

  These indicator values are also compatible with the lower reference level for existing exposure situations as per (ICRP 2007).

In addition, the limits set out in the StrlSchV apply to workers.

Facilities used for the final disposal of radioactive waste must be designed and operated in such a way that a maximum effective dose of 50 mSv cannot be exceeded in the area around the facility in the event of a worst-case design basis accident (§ 117(16) StrlSchV in conjunction with § 50 StrlSchV). This value is known as the design basis accident planning value. A design basis accident is an incident which, upon occurrence, would render it necessary to interrupt the

facility's operation or practices for safety reasons. The facility is designed to prevent such design basis accidents from occurring, or protective measures are provided for practices performed at the facility.

The 'Lex Asse' law abrogated these provisions when it comes to decommissioning the Asse II mine. In this case, the licencing authority may permit a higher value than the design basis accident planning value. However, the SSK is not aware of what this value will be and what method will be used to define it. This value should be defined as soon as possible so that retrieval and decommissioning planning can use the design basis accident planning value as a guide. From a radiological protection perspective, it would make little sense to define design basis accident planning values after planning has been completed. The SSK fundamentally rejects the definition of individual design basis accident planning values for individual facilities or practices covered by the provisions of §§ 49 and 50 StrlSchV. The design basis accident planning values should also be complied with when decommissioning the Asse II mine.

**Recommendation 2: Dose limits**

**Exposures resulting from the retrieval, interim storage, conditioning and final disposal of radioactive waste and in order to decommission the Asse II mine should be categorised as planned exposure situations. This means that the provisions of the StrlSchV to protect workers and the public apply. An effective dose limit of 1 mSv per year currently applies for the public in conjunction with the provisions of § 47 StrlSchV.**

**The SSK recommends to define design basis accident planning value for planning retrieval and decommissioning measures at the Asse II mine as soon as possible. The process used to define the design basis accident planning value for the effective dose should be presented in a clear and understandable manner. A design basis accident planning value higher than 50 mSv for the effective dose (§ 117(16) StrlSchV in conjunction with § 50 StrlSchV) should be avoided. If it is not possible to avoid deviations from this stipulation, they should be justified and discussed with stakeholders.**

### 4.3.6 Optimisation

Optimisation consists of the selection and implementation of options for action aimed at keeping exposure and environmental contamination as low as reasonably achievable, taking into account societal and economic factors. This is an iterative process which, in the present case, involves the following steps:

- Definition of objectives,
- Selection of a basic option,
- Planning of a main process, ancillary processes and supporting processes,
- Selection of the most-favourable technical options available to realise the processes, and
- Planning of work packages, and
- Planning and conducting individual work steps.

The various steps overlap one another. Thus, when selecting the basic option, the numerous technical options available to realise the process must already be planned and optimised so they do not subsequently change the outcome of the basic option decision to any significant extent.

Optimisation is a process based on the given circumstances and available knowledge as well as societal and economic factors. Measures for which planning and realisation require a prolonged period of time will see this basis change as time progresses. When retaining radioactive substances and decommissioning the Asse II mine, changes to the circumstances (e. g. a change to the state of the mine workings or inflow of solution) and available knowledge (e. g. as a result of ongoing investigations into the geological/hydrogeological situation, the state of the radioactive waste, and in terms of the development of retrieval technology) are to be expected. These changes may subsequently affect the actual benefit or assessment of the benefit of an option or realisation option. For this reason, an assessment should be performed in the event of major changes to circumstances or available knowledge in order to determine whether the pursued option or realisation option still complies with the optimisation requirement. To this end, the level of planning and realisation achieved and the disadvantages of making a change to the next steps in the process also need to be taken into consideration. In order to minimise the risk heralded by subsequent changes, the basic option should be selected on the basis of information backed up with a sufficient level of detail and evidence. The remaining imponderables should also be duly taken into account when making a decision. As already described, the lack of available knowledge means that this basic requirement is not fully met in the present case.

**Recommendation 3: Optimisation**

**Due to potential changes to the conditions (circumstances, available knowledge, societal and economic factors) surrounding the decommissioning of the Asse II mine, the SSK recommends using an iterative process to define measures to optimise retention of the radioactive materials and to decommission the Asse II mine.**

Among other things, proper optimisation requires a full and objective analysis of consequences, i.e. an analysis of the advantages and disadvantages of the respective option or realisation option.

Some consequences may be more relevant than others. In general, when providing an estimate of consequences, the further in the future the consequence, the higher the uncertainties. When estimating a consequence, it is therefore inevitable and, in order to limit the amount of work and effort required, expedient to choose the type, scope and level of detail based on relevance and predictability. Each estimate should be accompanied by their given uncertainties. Quantitative estimates should, for example, be provided in the form of bands. A uniform level of conservatism or realism should be established in order to ensure proper optimisation.

In terms of radiological criteria as well as exposures involving occupationally exposed persons and individual members of the public, the SSK notes that exposures during planned measures and expected system development should be taken into account along with exposures attributable to unplanned events and less probable system developments. This applies to events that occur in the mine, such as uncontrolled flooding before completion of decommissioning, and to (design basis) accidents, e. g. during surface-level interim storage of radioactive waste. If radioactive waste is to be retained in the mine, this will also affect the further development of the mine after it has been decommissioned.

Additional radiological protection measures can be put in place to reduce each exposure involving occupationally exposed persons and individual members of the public. However, above a certain level, the required natural and societal resources may render such radiological protection measures disproportionate. The SSK therefore deems it necessary to take the ‘consumption of natural resources’ and ‘consumption of societal resources’ criteria into account during optimisation.

In terms of completeness of subsequent developments and subsequent measures, the SSK would like to point out that retrieval of the radioactive waste stored in the Asse II mine would – without question – involve the conditioning, transport, long-term interim storage and final disposal of said radioactive waste at the site or another selected site.

The final disposal site for the radioactive waste retrieved from the Asse II mine following emplacement in an interim storage facility yet to be constructed still remains unclear. The comparison of options (BfS 2010a) states that the retrieved radioactive waste should be transported to a licenced repository, but there is no such repository available at present. The National Programme (BMUB 2015) describes the situation as follows:

"*Furthermore, the radioactive waste to be retrieved from the Asse II mine is to be taken into account in the search for a site for this disposal facility.* […] *It will only be possible to reach a final decision on the location of the disposal facility site for this waste, taking into account all technical, economic and political aspects, once the criteria for emplacement in the disposal facility site based on the Site Selection Act have been determined and sufficient information is available regarding the accumulation time, volume and properties of the radioactive waste to be retrieved from the Asse II mine."*

The SSK understands that an approach has not yet been defined to characterise the waste in line with the requirements of the repository to be determined and the terms laid down in water legislation. Based on experiences gleaned from the Konrad disposal facility, this will be a time-consuming process involving exposures to workers.

Interim storage, likely to span several decades, will be required until the repository is available. Stability within society is essential to safe long-term interim storage as unfavourable societal developments could prevent the performance of measures put in place to promote safety (refer to AkEnd 2002).

The reference period for the retrieved radioactive waste shall continue until the waste has undergone final disposal at a future repository. The reference period for the Asse II mine and the radioactive substances stored there should be defined such that it largely covers the potential transfer of radioactivity to environmental media near the surface. In particular, when it comes to radiologically unfavourable developments, the reference period must include the time at which the radionuclide concentrations are at their highest in the environmental media.

The SSK notes that the optimisation process must include a consideration of

- the additional exposures to workers and the public that are expected to occur during decommissioning, i.e. in the foreseeable future,
- the additional exposures to workers and the public that may occur during decommissioning, i.e. in the foreseeable future, due to (design basis) accidents ('risks'), and
- the potential public exposures calculated for the distant future with a high degree of uncertainty,

along with due consideration of the proportionality of the resources used to ensure radiological protection as well as other pertinent societal needs and interests.

Optimisation should be performed using assumptions regarding current and future burdens that are as realistic as possible in order to ensure a balanced consideration of the exposure and risks to current and future generations.

The information required to achieve this must be specifically procured as soon as possible so as to be able to assess various optimisation options at the earliest opportunity.

The SSK therefore welcomes the fact that the suspended geological and hydrogeological exploration work has now been resumed.

**Recommendation 4: Performing optimisation**

**When performing optimisation for the Asse II mine, the SSK not only recommends the overall process of retrieval, conditioning, characterisation and long-term interim waste storage, it also advises that investigations be performed regarding the retention of waste. Analyses of consequences are a key aspect of optimisation as they allow for an assessment of the effects of changes made during the planning and implementation phase. Since it is not possible to rule out the need to store large quantities of waste in the mine because, for example, an uncontrollable inflow of solution occurs before or during retrieval, or if retrieval has to be halted in line with the 'Lex Asse' criteria, the analyses of consequences should also include a scenario where all or part of the waste is retained in the mine. Optimisation should also extend to consumption of resources.**

## 4.4 Fact-finding

In April 2010, the BfS submitted a concept (DMT and TÜV Nord 2010) relating to the fact-finding process demanded in the comparison of options. Fact-finding should serve to provide information about the state of the emplacement mine workings and the radioactive waste stored there. According to the BfS, this information is essential in order to be able to assess the feasibility of retrieval, review its justification, and subsequently decide on and plan retrieval (BfS 2011).

Fact-finding should take place by way of the following three steps:

1. Drill into the two emplacement chambers (7 and 12)
2. Open both emplacement chambers
3. Perform a trial removal of waste containers from the chambers (approx. 350 waste containers from chamber 7 and around 150 waste containers from chamber 12).

The stability of the chambers and pillars, and the design of the sealing structures should be clarified prior to drilling into the two chambers. An investigation should be performed to establish whether there are any cavities in the chambers and to determine the prevailing atmospheric conditions in terms of radioactive and explosive gases. At the same time, this investigation should ascertain whether any saline solutions are present in the chambers and to what extent radioactive substances have dispersed there.

Based on the state of planning in 2013, step 1 of the fact-finding process should be finished in 2018, with step 2 being performed in 2024 and step 3 scheduled for completion in 2031 (Arcadis 2013). As a result, the three-year period required for the fact-finding process that was assumed in the comparison of options has grown to a period of almost 20 years.

On 15 April 2015, the BfS presented a report suggesting 'optimisation of the fact-finding process' (BfS 2015). One proposal aimed at accelerating this process is to skip steps 2 and 3 for chambers 7 and 12.

Exploration of the emplacement chambers is an extremely important prerequisite for substantiated planning to ensure that retrieval can be performed safely and to determine the

associated radiological consequences along with the amount of time required, the amount of natural and societal resources required, and the risks associated with retrieval.

In principle, the SSK welcomes the approach the BfS has chosen with regard to fact-finding. The SSK posits that 'optimisation of the fact-finding process' is necessary as the risks associated with the prolonged period of time required to perform fact-finding should be minimised. However, the SSK does not agree with the reasons the BfS put forward in favour of reducing the scope of the fact-finding process. Even if the BfS does not consider it necessary to justify retrieval from a legal perspective, it is imperative for the planning phase to establish the consequences of retrieval and the collective dose to workers. Any lack of information in this regard would make it extremely difficult to comply with the radiological protection principle of optimisation.

## 4.5 Determining exposure

The potential doses to occupationally exposed persons and to individual members of the public as a result of practices in connection with decommissioning the Asse II mine should be determined as realistically as possible in order to ensure that the results can be used, e. g. as a basis for optimising radiological protection. For guidance purpose, the SSK recommendation on determining exposure (SSK 2013) should be consulted. Realistic assumptions should also be provided when estimating the exposures to be expected during decommissioning work.

**Recommendation 5: Determining exposure**

**The SSK recommends that exposures to occupationally exposed persons and individual members of the public as a result of practices performed until the completion of decommissioning work at the Asse II mine and the final disposal of radioactive waste be performed as realistically as possible so they can be used as a basis for optimisation. For guidance purpose, the SSK recommendation on determining exposure (SSK 2013) should be consulted.**

**When estimating potential doses following decommissioning of the Asse II mine and after emplacement of the radioactive waste in a repository, the SSK recommends that conservative assumptions be avoided wherever possible.**

## 4.6 Radiological requirements placed on long-term safety

Assuming that radioactive waste is to be retained in the Asse II mine, the mine must be viewed as a repository. Assessing the long-term safety of a repository is a central aspect of any repository project as it serves to prove that humans and the environment are protected against the long-term radiological risks associated with a repository. In addition, care must be taken to protect the groundwater from radioactive waste and other kinds of waste, and to maintain the surface infrastructure.

In their joint recommendation from 2008 (RSK/SSK 2008), the Reactor Safety Commission (Reaktor-Sicherheitskommission, RSK) and the SSK noted that exposure predictions for the distant future are associated with major uncertainties and that dose considerations during final disposal constitute indicator quantities which, together with other criteria, allow the long-term safety of a repository to be estimated. In their recommendation, the RSK and SSK proposed effective dose indicator values of 0.1 mSv per year for probable developments and 1 mSv per year for less probable developments in order to assess long-term safety.

These values are consistent with protection standards for the current generation, meaning that they meet the requirements placed on intergenerational equity laid down in (ICRP 2013), Section 3.1: *"(16) In ICRP Publication 81 the Commission recommends that 'individuals and populations in the future should be afforded at least the same level of protection as the current generation' (ICRP, 1998, Para. 40). This basic principle is broadly consistent with the requirement of the 1997 Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management stating that individuals, society and the environment should be protected from the harmful effects of ionising radiation, now and in the future, in such a way that: 'the needs and aspirations of the present generation are met without compromising the ability of future generations to meet their needs and aspirations' (IAEA, 1997)."*

As a result, in (SSK 2010) the SSK recommended these values also be applied when decommissioning the Morsleben repository. The SSK holds the view that the same criteria must also be applied when assessing potential future exposures following decommissioning of the Asse II mine.

**Recommendation 6: Requirements placed on the long-term safety assessment**

**Assuming that radioactive waste is to be retained in the Asse II mine, the mine must be viewed as a repository. Assessing the long-term safety of a repository is a central aspect of any repository project as it serves to prove that humans and the environment are protected against the long-term risks associated with a repository. Alongside radiological protection, care must be also taken to protect the groundwater and to maintain the surface infrastructure.**

**Long-term safety should be assessed using the principle of application of dose limits, e. g. by using indicator values (target values). The SSK recommends that the long-term safety requirements for the Morsleben repository for radioactive waste (ERAM) it recommended in (SSK 2010) also be applied to the Asse II mine. In particular, the SSK recommends using individual public dose indicator values of 0.1 mSv per year for probable developments and 1 mSv per year for less probable developments as criteria for evaluating potential doses over prolonged periods.**

## 4.7 Analyses of consequences and long-term safety assessment

Analyses of consequences are an essential basis for optimising the protection of workers and the public. They also form part of the assessments required to furnish proof of long-term safety. Analyses of consequences are therefore needed for the 'retrieval' option and if radioactive substances are to be retained in the mine. Nevertheless, variations of such analyses should be considered depending on the option to be investigated.

Consequences of analyses must focus on the entire process pertaining to decommissioning of the Asse II mine, including operation of the mine, all measures including those used to improve the given level of knowledge (e. g. fact-finding during the planning and preparatory phase), performing decommissioning (including measures to secure or retrieve the waste), treatment and interim storage of the waste, and final disposal of the waste in a repository. Risks associated with (design basis) accidents form part of analyses of consequences. Due to the long planning and performance period associated with decommissioning the mine and storing the radioactive waste at an interim storage facility, and given the constantly growing level of knowledge

available, the analyses of consequences should be reviewed on a regular basis. The onset of unforeseen events may also give rise to the need to review the analyses of consequences.

As it is not possible to rule out the potential prolonged interim storage of retrieved radioactive waste, the SSK considers it necessary to take scenarios into account where future societal developments could prevent the performance of measures put in place to promote safety.

**Recommendation 7: Analyses of consequences**

**In order to optimise protection for occupationally exposed persons and individual members of the public, the SSK recommends performing analyses of consequences that include the entire process of decommissioning the Asse II mine, beginning with the planning phase and continuing right through to final disposal of the waste. In doing so, radiological protection factors should be considered along with other risks such as work accidents and the consumption of natural and societal resources.**

**Analyses of consequences also need to include unplanned events such as (design basis) accidents, e. g. flooding of the mine before or during retrieval, and less probable system developments as well as halting retrieval in line with the 'Lex Asse' criteria.**

**Analyses of consequences should be subject to regular reviews and updated in line with the latest findings. The results of the analyses must be used in the optimisation process for planning and implementation.**

Section 4.2 explained that the BfS considers the complete backfilling option to be unfeasible due to its uncertainty about being able to perform a long-term safety assessment. The SSK does not share this view. It is not possible to ensure decommissioning of the Asse II mine solely by opting for the 'retrieval' option. It must also be assumed that retrieval may be halted at any given point in the process to plan, prepare for and carry out retrieval. This could be due to the onset of conditions set out in 'Lex Asse' (Lex Asse 2013), or because of an uncontrollable inflow of solution or other currently unforeseeable events or conditions. For this reason, conditions need to be created that enable radioactive substances to be retained in the mine and safely sealed there.

The SSK would like to point out that there are no plans to perform full retrieval of the radioactive substances stored in the Asse II mine and, based on the current level of knowledge, the amount of effort required to perform retrieval would rise significantly for the following reasons:

- Part of the sorel cement used in the Asse II mine was and is manufactured using contaminated saline solution.
- There are no plans to lift and dispose of the contaminated saline solutions currently located on the discarded levels in the deep exposure.
- Radioactivity has penetrated into the excavation-disturbed zone below the emplacement chambers at the 750 m level. It has not yet been decided whether and to what extent this radioactivity is to be removed.

For this reason alone, an analysis of consequences and investigations into long-term safety should form part of the plan approval procedure when decommissioning the Asse II mine, even if the radioactive waste has been retrieved to the greatest possible extent. As described above,

other reasons may give rise to the need to retain waste in the mine on a larger scale, e. g. if retrieval has to be halted.

In light of such reasons, investigations based on the latest advances in science and technology should be performed to provide a basis for assessing and ensuring long-term safety. Despite current gaps in knowledge, the SSK expects such an assessment to be possible. In contrast to the situation presented by the BfS in 2010, which posited that there was not enough time available, the delay for the project as a whole does in fact provide enough time to carry out the analyses required for the long-term safety assessment.

**Recommendation 8: Long-term safety assessment**

**As it can be assumed that part of the radioactive waste will be retained in the mine, and since retrieval may be halted at any time during the process to plan, prepare and carry out retrieval, the SSK recommends performing the investigations needed to retain and seal radioactive substances in the Asse II mine with the aim of conducting a long-term safety assessment in line with the latest advances in science and technology. In order to avoid delays to work currently being carried out in preparation for decommissioning, the SSK recommends performing the necessary investigations at the same time as the ongoing stabilisation and precautionary measures, fact-finding process, and work being conducted to prepare for retrieval of the radioactive waste.**

**The SSK would like to point out that these investigations should still be conducted even if retrieval is performed in as complete a manner as possible due to the presence of any remaining radioactive substances. Such investigations are all the more necessary if retrieval has to be halted for any reason.**

## 4.8 Data and information

The better and more reliably the rock, shaft, emplacement chambers, waste containers and waste can be described and assessed, the more successful the decommissioning process will be in terms of the aim to protect current and future generations and the environment in the best-possible way. This also applies to the results of the analyses of consequences, which clearly require a realistic description so that their results have as great an impact as possible. The information required to achieve this must be specifically procured as soon as possible to as to be able to assess various optimisation options at the earliest opportunity.

**Recommendation 9: Data and information**

**The SSK recommends expediting efforts to gather information for the main parameters used in analyses of consequences and long-term safety assessments.**

**Due to the known uncertainties regarding key information, the SSK recommends a systematic, iterative process be put in place to gather information, identify knowledge gaps, collect data, determine consequences and analyse uncertainties.**

**The SSK recommends that the results of uncertainty and sensitivity analyses be conveyed in a timely manner along with any major lack of information as part of an open and transparent process. When**

**communicating results, suggestions should also be provided as to how and by when knowledge gaps are to be resolved. Conservative assumptions should be used if any information is unavailable, but they should be clearly designated as such and avoided whenever possible.**

## 4.9 Emergency preparedness and response

The Asse II mine needs to be sufficiently stable in order for it to remain open so fact-finding can be performed and the radioactive waste can be retrieved. However, the mine's current state presents a number of major challenges in terms of keeping it open in the long term. The former operator, GSF (now known as HGMU), planned to decommission the mine and close it in 2016. This is why maintenance work was adapted to this time schedule, which applies to the mine plant and various other technical equipment. The mine workings are becoming increasingly unstable with convergence in the heavily excavated mine causing an increasing loss of integrity due to major deformations since the supporting structures are insufficient and the protective layers are not thick enough.

The old underground chambers of the Asse II mine were backfilled using own material between 1980 and 1989 in order to counter the loss of integrity due to convergence. From August 1995 to April 2004, residual salt from the stockpile at the former potash mine in Ronnenberg near Hanover was brought to the Asse II mine and used to backfill the old underground chambers, particularly the unstable southern flank. A total of 2,213,700 megagrams of material was backfilled upon completion in 2004. As a result of backfilling the southern flank to stabilise it, convergence then occurred in the central area of the mine which is now threatening parts of the infrastructure that are imperative to operations. Given its current state of development, the Asse II mine is increasingly losing its integrity and gradually becoming unfit for its intended purpose.

According to the unrealistic model calculations from the GRS, the beyond-design-basis inflow of solutions from the overburden would not enable the radiological protection objectives to be met without suitable measures (GRS 2009). In its report on emergency planning dated 28 February 2010 (BfS 2010b), the BfS concurred with this view: "*This rendered it necessary to investigate whether and to what extent options are available to influence the likelihood of occurence and/or the radiological consequences of beyond-design-basis inflow of solutions into the Asse II mine during operation.*"

In (BfS 2010b) this emergency is defined as a beyond-design-basis event or beyond-design-basis sequence of events that would prevent the mine from remaining open or being decommissioned in the future, while also giving rise to the need for emergency measures to secure the mine and the radioactive waste stored there. All of the emergency plans are aimed at limiting the consequences of beyond-design-basis events, improving the state of the Asse II mine, and minimising the consequences of beyond-design-basis events both in and around the mine.

The BfS distinguishes between precautionary and emergency measures. Precautionary measures are measures performed to stabilise the mine workings and to protect the emplacement chambers by backfilling the remaining cavities and by building sealing structures. Measures to ensure emergency preparedness include improving the management and collection of inflowing solutions, planning emergency measures, ensuring the supply of building materials, and providing the requisite material resources to produce building materials and backfill, e. g. the procurement of $MgCl_2$ solution to counterflood the mine workings.

In the event of an emergency in the mine, emergency measures should include backfilling the residual cavities in the low active waste emplacement chambers with brucite, final sealing of the medium active waste chambers' emplacement zone by backfilling it with sorel cement, and flooding the mine with $MgCl_2$ solution to protect it against solution processes. Shafts two and four should then be sealed and backfilled before leaving the mine.

According to the BfS, emergency preparedness, i.e. the ability to immediately initiate emergency measures, is a prerequisite for opening up emplacement chambers. The BfS originally planned to have emergency preparedness in place by 2016, but this is currently not expected to be the case until 2024 (Arcadis 2013).

The ESK and SSK previously issued a joint statement evaluating the emergency plan provided by the BfS for the Asse II mine (ESK/SSK 2013). This statement analysed the prevailing situation in the mine, in particular the rock-mechanical state of the mine workings and the potential development of the inflow of solution from the overburden, and subsequently evaluated the emergency plan provided by the BfS. In their evaluation, the ESK and SSK issued recommendations for the following points: Necessity and priority of ensuring the mine remains fit for its intended purpose, precautionary and emergency measures (detailed emergency measure plans, preparation of emergency scenarios, classification of precautionary and emergency measures), an emergency plan and emergency organisation, criteria to establish an emergency, rectification of administrative issues, prioritisation and immediate performance of precautionary measures, influence of fact-finding on emergency preparedness, and planning and preparation of retrieval.

Emergency planning may be deemed sufficient provided that the ESK and SSK recommendations are implemented.

## 4.10 Transparency and the general public

Based on the latest international state of science and technology, undertakings that may considerably affect third parties must involve relevant stakeholders in said undertakings. Stakeholders are persons and societal groups with an interest in certain (decision-making) processes or who may be affected by situations and events resulting from such processes. When handling radioactive waste, for example, this may include all of the organisations and authorities involved in planning and performing measures, those affected by measures (e. g. people who live near the mine and the envisaged interim disposal facility and repository), societal groups (e. g. religious congregations, trade unions, environmental organisations) and citizens' initiatives as well as individual citizens. It should be considered a given that expert commissions such as the ESK and SSK are involved in such processes and measures.

The SSK already pointed out the importance of stakeholder involvement when conveying experiences gleaned from the Fukushima reactor accident (SSK 2015).

The OECD/NEA reviewed stakeholder involvement in waste management and emergency preparedness and response (NEA 2011, NEA 2015), for example, and noted that a broad spectrum of stakeholders needs to be involved. Among other things, the OECD/NEA works provide suggestions on how to initiate a 'stakeholder concept'. The ICRP also considers stakeholder involvement a key factor in optimising radiological protection as it is needed to foster acceptance for decisions pertaining to radiological protection along with their implementation and efficiency (ICRP 2006).

**Recommendation 10: Transparency and the general public**

**In the future, stakeholders need to be involved in an open and transparent communication process when decisions are taken regarding measures in connection with decommissioning the Asse II mine, such as retrieval, interim storage, conditioning and final disposal. To this end, the SSK recommends the establishment of a broad support process along with a decision as to who is deemed a stakeholder, who should be involved in which process, the extent of intended involvement (provided with information, involved in discussions or accorded full involvement, also as a partner while developing and implementing solutions, particularly planning solutions), and the processes in which stakeholders are to be involved.**

## References


| | |
|---|---|
| AF-Colenco AG 2009 | AF-Colenco AG. Schachtanlage Asse II – Abschätzung der Trinkwasserdosis bei einem unterstellten Absaufen des Grubengebäudes. Memo 1299/04(V1), Baden-Dättwil 08.05.2009 |
| AF-Colenco AG et al. 2009 | AF-Colenco AG. Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH, IfG Institut für Gebirgsmechanik GbH. Schachtanlage Asse II, Beschreibung und Bewertung der Stilllegungsoption Vollverfüllung. Baden-Dättwil/Braunschweig/Leipzig 01.10.2009. http://www.bfs.de/SharedDocs/Downloads/Asse/DE/studien-gutachten/optionen/2009-10-afc-grs-ifg-machbarkeitsstudie-vollverfuellung.pdf, zuletzt aufgerufen am 28.09.2016 |
| AkEnd 2002 | Arbeitskreis Auswahlverfahren Endlagerstandorte (AkEnd). Auswahlverfahren für Endlagerstandorte, Empfehlungen des AkEnd – Arbeitskreis Auswahlverfahren Endlagerstandorte. Dezember 2002. https://www.bfs.de/SharedDocs/Downloads/BfS/DE/berichte/ne/langfassung-abschlussbericht-akend.pdf, zuletzt aufgerufen am 28.09.2016 |
| Arcadis 2013 | Arcadis. Projekt Schachtanlage Asse II, 2. Zwischenbericht zur Fortschreibung der Projektablaufplanung zum Stand 31.03.2013. http://www.bfs.de/SharedDocs/Downloads/Asse/DE/studien-gutachten/rueckholung/2013-03-arcadis-projektablaufplanung-rueckholung.pdf, zuletzt aufgerufen am 28.09.2016 |
| AtG 1985 | Gesetz über die friedliche Verwendung der Kernenergie und den Schutz gegen ihre Gefahren (Atomgesetz) in der Fassung der Bekanntmachung vom 15. Juli 1985 (BGBl. I S. 1565), das durch Artikel 1 des Gesetzes vom 26. Juli 2016 (BGBl. I S. 1843) geändert worden ist |

BfS 2007 Bundesamt für Strahlenschutz (BfS). Prüfung von Unterlagen zur Schließung der Schachtanlage Asse II im Hinblick auf die Anforderungen eines atomrechtlichen Planfeststellungsverfahrens, 26.09.2007. www.bmub.bund.de/fileadmin/bmu-import/files/pdfs/allgemein/application/pdf/bericht_schachtanlage_asse_ii.pdf, zuletzt aufgerufen am 28.09.2016

BfS 2010a Bundesamt für Strahlenschutz (BfS). Optionenvergleich Asse, Fachliche Bewertung der Stilllegungsoptionen für die Schachtanlage Asse II. BfS- 19/10, Salzgitter, Januar 2010, urn:nbn:de:0221-201004141430

BfS 2010b Bundesamt für Strahlenschutz (BfS): Notfallplanung für das Endlager Asse, Stand: 28.Februar 2010, urn:nbn:de:0221-2013070410956

BfS 2010c Bundesamt für Strahlenschutz (BfS). Berechnungsgrundlagen zur Ermittlung der Strahlenexposition infolge bergbaulicher Umweltradioaktivität (Berechnungsgrundlagen Bergbau). März 2010, urn:nbn:de:0221-20100329966/3

BfS 2011 Bundesamt für Strahlenschutz (BfS): Kriterienbericht Faktenerhebung – Kriterien zur Bewertung der Ergebnisse der Faktenerhebung. Stand: 01. Dezember 2011, urn:nbn:de:0221-201201097015

BfS 2014 Bundesamt für Strahlenschutz (BfS): Schachtanlage Asse II, Gesamtdarstellung zur Rückholungsplanung Stand: Januar 2014. BfS-25/14, Salzgitter, Februar 2014, urn:nbn:de:0221-2014021211169

BfS 2015 Bundesamt für Strahlenschutz (BfS): Evaluierung der Faktenerhebung und der Vorgehensweise zur Rückholung. Salzgitter, 15. April 2015. http://www.bfs.de/SharedDocs/Downloads/Asse/DE/IP/stellungnahmen/150415-evaluierung-faktenerhebung-vorgehensweise-rueckholung.pdf, zuletzt aufgerufen am 28.09.2016

BMI 1983 Bundesministerium des Innern (BMI). Sicherheitskriterien für die Endlagerung radioaktiver Abfälle in einem Bergwerk, GMBl. 1983

BMU 2008 Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU). Kabinett beschließt Betreiberwechsel für Asse – Stilllegung der Asse erfolgt nach Atomrecht. Pressemitteilung Nr. 245/08, Berlin, 05.11.2008. www.bmub.bund.de/N42519, zuletzt aufgerufen am 28.09.2016

BMU 2012 Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU). Allgemeine Verwaltungsvorschrift zu § 47 der Strahlenschutzverordnung (Ermittlung der Strahlenexposition durch die Ableitung radioaktiver Stoffe aus Anlagen oder Einrichtungen) vom 28.08.2012, Banz AT 05.09.2012 B1

| | |
|---|---|
| BMUB 2015 | Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (BMUB). Programm für eine verantwortungsvolle und sichere Entsorgung bestrahlter Brennelemente und radioaktiver Abfälle (Nationales Entsorgungsprogramm. August 2015. http://www.bmub.bund.de/fileadmin/Daten_BMU/Download_PDF/Nukleare_Sicherheit/nationales_entsorgungsprogramm_aug_bf.pdf, zuletzt aufgerufen am 01.08.2016 |
| Deutscher Bundestag 2013 | Deutscher Bundestag. Stenografischer Bericht. 225. Sitzung. Plenarprotokoll 17/225. Berlin, 28. Februar 2013 |
| DMT und TÜV Nord 2009 | DMT GmbH & Co. KG, TÜV NORD SysTec GmbH & Co. KG. Beurteilung der Möglichkeit einer Rückholung der LAW-Abfälle aus der Schachtanlage Asse. Essen/Hamburg 25.09.2009. http://www.asse.bund.de/SharedDocs/Downloads/Asse/DE/IP/studien-gutachten/2010/rueckholung-untersuchungskonzept-faktenerhebung.html, zuletzt aufgerufen am 28.09.2016 |
| DMT und TÜV Nord 2010 | DMT GmbH & Co. KG, TÜV NORD SysTec GmbH & Co. KG. Faktenerhebung zur Rückholung der radioaktiven Abfälle aus dem Endlager Asse - Schritt 1: Untersuchungskonzept zum Anbohren der Einlagerungskammern 7/750 und 12/750. Untersuchungsbericht Nr. U2248-BfS-G, 14.04.2010. http://www.asse.bund.de/SharedDocs/Downloads/Asse/DE/studien-gutachten/rueckholung/2010-04-dmt-untersuchungskonzept-faktenerhebung.pdf, zuletzt aufgerufen am 28.09.2016 |
| ESK/SSK 2008 | Entsorgungskommission (ESK) und Strahlenschutzkommission (SSK). Gemeinsame Stellungnahme der ESK und der SSK zur Schachtanlage Asse II – Empfehlungen für Untersuchungen. Gemeinsame Stellungnahme der Strahlenschutzkommission und der Entsorgungskommission, verabschiedet in der 228. Sitzung der SSK am 28.10.2008 und in der 4. Sitzung der Entsorgungskommission am 06.11.2008. In: Empfehlungen und Stellungnahmen der Strahlenschutzkommission 2008. Veröffentlichungen der Strahlenschutzkommission, Band 67, H. Hoffmann GmbH - Fachverlag, Berlin, 2011, ISBN 978-3-87344-167-5 |
| ESK/SSK 2013 | Entsorgungskommission (ESK) und Strahlenschutzkommission (SSK). Notfallplanung für die Schachtanlage Asse II. Gemeinsame Stellungnahme der Entsorgungskommission und der Strahlenschutzkommission, verabschiedet in der 262. Sitzung der SSK am 11./12. Juli 2013 und in der 34. Sitzung der ESK am 11. Juli 2013, BAnz AT 18.11.2013 B3; urn:nbn:de:101:1-201308192122 |

| | |
|---|---|
| ESK/SSK-Ad-hoc-Arbeitsgruppe ASSE 2009 | ESK/SSK-Ad-hoc-Arbeitsgruppe ASSE 2009. Anlage zum Schreiben an das BMU vom 02.11.2009: Zur Unterlage „Abschätzung potentieller Strahlenexpositionen in der Umgebung der Schachtanlage Asse II in Folge auslegungsüberschreitender Zutrittsraten der Deckgebirgslösung während der Betriebsphase“. http://www.entsorgungskommission.de/sites/default/files/downloads/anlagestrahlenexpositionenhomepage.pdf, zuletzt aufgerufen am 28.09.2016 |
| Euratom 2014 | Rat der Europäischen Union: Richtlinie 2013/59/Euratom des Rates vom 5. Dezember 2013 zur Festlegung grundlegender Sicherheitsnormen für den Schutz vor den Gefahren einer Exposition gegenüber ionisierender Strahlung und zur Aufhebung der Richtlinien 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom und 2003/122/Euratom, Amtsblatt der Europäischen Union, L 13/1, 17.1.2014 |
| EWN und TÜV Nord 2008 | EWN GmbH, TÜV Nord Sys Tec GmbH & Co. KG. Möglichkeit einer Rückholung der MAW-Abfälle aus der Schachtanlage Asse, Lubmin/Hamburg 28. November 2008. http://www.asse.bund.de/SharedDocs/Downloads/Asse/DE/studien-gutachten/2008-11-ewn-tuev-rueckholung-maw-studie.pdf, zuletzt aufgerufen am 28.09.2016 |
| GRS 2009 | Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH. Abschätzung potenzieller Strahlenexpositionen in der Umgebung der Schachtanlage Asse II infolge auslegungsüberschreitender Zutrittsraten der Deckgebirgslösung während der Betriebsphase. Braunschweig 21.04.2009 |
| GRS 2010 | Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH. Schachtanlage Asse: Stellungnahme zur Wirksamkeit von Einzelmaßnahmen der Notfallplanung. GRS -A-3520, Braunschweig 26.04.2010 |
| GSF 2006 | GSF. Herleitung und Beschreibung des Konzepts zur Schließung der Schachtanlage Asse. 02.10.2006. http://www.asse.bund.de/SharedDocs/Downloads/Asse/DE/IP/historische-dokumente/stilllegungskonzept-hmgu/12-schliessungskonzept.pdf, zuletzt aufgerufen am 28.09.2016 |
| IAEA 2011 | International Atomic Energy Agency (IAEA). Disposal of radioactive waste – specific safety requirements. IAEA Safety Standards Series No. SSR-5, Wien, 2011, ISBN:978-92-0-103010-8 |
| ICRP 2007 | International Commission on Radiological Protection (ICRP). The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103, Ann. ICRP 37 (2-4), Elsevier, 2007, ISBN 978-0702030482 |

ICRP 2013 International Commission on Radiological Protection (ICRP). Radiological protection in geological disposal of long-lived solid radioactive waste. ICRP Publication 122. Ann. ICRP 42(3), Elsevier, 2013, ISBN 978-0-7020-5505-8

Krupp 2009 Krupp RE. Strömungs- und Transportmodell, Langzeitsicherheit Asse II. 29.12.2009. https://www.ptka.kit.edu/downloads/ptka-wte-e/WTE-E-BPub-AGO-Stellungnahme_zur_Beantwortung_BMU-Fragen_zum_Hydromodell_Krupp-2009-12-29.pdf, zuletzt aufgerufen am 28.09.2016

Lex Asse 2013 Gesetz zur Beschleunigung der Rückholung radioaktiver Abfälle und der Stilllegung der Schachtanlage Asse II. Bundesgesetzblatt Jahrgang 2013, Teil I Nr. 19, ausgegeben zu Bonn am 24. April 2013, p. 921f.

NEA 2011 Nuclear Energy Agency (NEA). Practices and Experience in Stakeholder Involvement for Post-nuclear Emergency Management, Summary of the Workshop organized by the OECD Nuclear Energy Agency (NEA) Committee on Radiation Protection and Public Health (CRPPH) 12-14 October Bethesda, Maryland, United States, hosted by the NRC. NEA No. 6994. OECD 2011, ISBN 978-92-64-99166-8

NEA 2015 Nuclear Energy Agency (NEA). Stakeholder Involvement in Decision Making: A Short Guide to Issues, Approaches and Resources. NEA No. 7189. OECD 2015. http://www.oecd-nea.org/rwm/pubs/2015/7189-stakeholder-involvement-2015.pdf, zuletzt aufgerufen am 28.09.2016

Öko-Institut 2012 Öko-Institut e.V. Modellierung des Transports von Radionukliden durch Gesteinsschichten und der resultierenden Strahlenexposition von Referenzpersonen: Berechnungen mit Parametern der Schachtanlage Asse II. Darmstadt, 21.5.2012. http://www.oeko.de/oekodoc/1263/2012-159-de.pdf, zuletzt aufgerufen am 28.09.2016

RSK/SSK 2008 Reaktor-Sicherheitskommission (RSK) und Strahlenschutzkommission (SSK). Gemeinsame Stellungnahme der RSK und der SSK zum GRS-Bericht „Sicherheitsanforderungen an die Endlagerung hochradioaktiver Abfälle in tiefen geologischen Formationen“. Gemeinsame Stellungnahme der Strahlenschutzkommission und der Reaktor-Sicherheitskommission, verabschiedet in der 224. Sitzung der SSK am 03.07.2008 und in der 408. Sitzung der RSK am 09.05.2008. In: Empfehlungen und Stellungnahmen der Strahlenschutzkommission 2008. Veröffentlichungen der Strahlenschutzkommission, Band 67, H. Hoffmann GmbH - Fachverlag, Berlin, 2011, ISBN 978-3-87344-167-5

SSK 2008 Strahlenschutzkommission (SSK). Organisation und Durchführung des Strahlenschutzes in der Schachtanlage Asse II (Hintergrundinformation der SSK zur gemeinsamen Stellungnahme der ESK und der SSK zur Schachtanlage Asse II – Plausibilitäts-prüfungen von Angaben des Betreibers). Stellungnahme der Strahlenschutzkommission, verabschiedet in der 227. Sitzung der SSK am 25./26.09.2008. In: Empfehlungen und Stellungnahmen der Strahlenschutzkommission 2008. Veröffentlichungen der Strahlen-schutzkommission, Band 67, H. Hoffmann GmbH - Fachverlag, Berlin, 2011, ISBN 978-3-87344-167-5

SSK 2010 Strahlenschutzkommission (SSK). Radiologische Anforderungen an die Langzeitsicherheit des Endlagers für radioaktive Abfälle Morsleben (ERAM). Empfehlung der Strahlenschutzkommission, verabschiedet in der 246. Sitzung der SSK am 02./03.12.2010. BAnz Nr. 138 vom 13.09.2011, S. 3189

SSK 2013 Strahlenschutzkommission (SSK). Ermittlung der Strahlenexposition. Empfehlung der Strahlenschutzkommission, verabschiedet in der 269. Sitzung der SSK am 12.09.2013. BAnz AT 23.05.2014 B4; urn:nbn:de:101:1-201405079359

SSK 2015 Strahlenschutzkommission (SSK). Weiterentwicklung des Notfallschutzes durch Umsetzen der Erfahrungen aus Fukushima. Empfehlung der Strahlenschutzkommission, verabschiedet in der 274. Sitzung der Strahlenschutzkommission am 19./20.02.2015. BAnz AT 04.01.2016 B3; urn:nbn:de:101:1-201512213326

StrlSchV 2001 Verordnung über den Schutz vor Schäden durch ionisierende Strahlen (Strahlenschutzverordnung – StrlSchV) vom 20. Juli 2001 (BGBl. I S. 1714; 2002 I S. 1459), die zuletzt durch Artikel 5 der Verordnung vom 11. Dezember 2014 (BGBl. I S. 2010) geändert worden ist