Note:
This is a translation of the RSK statement entitled
"Zusammenfassende Stellungnahme der RSK zu zivilisatorisch bedingten Einwirkungen, Flugzeugabsturz"
In case of discrepancies between the English translation and the German original, the original shall prevail.

RSK Statement

(524th meeting of the Reactor Safety Commission (RSK) on 20 October 2021)

Summary statement of the RSK on man-made hazards, aircraft crash

STATEMENT

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1 Introduction

On 17 March 2011, in connection with the events at the Fukushima plant in Japan, the Federal Environment Ministry requested the Reactor Safety Commission (RSK) to draw up a catalogue of requirements for a safety review of the German nuclear power plants and to evaluate the results of such a review on the basis of certain criteria. The subject of this safety review was the assessment of the robustness of the German nuclear power plants against beyond-design-basis events.

To classify the results of the safety review, the RSK defined graded criteria for robustness. Here, a distinction is made between robustness levels for natural hazards, postulates and emergency measures and robustness-related degrees of protection for the man-made hazards that also have to be considered according to the RSK catalogue of requirements.

With regard to the man-made hazard of an aircraft crash, the following degrees of protection have been defined for the control of such events:

Mechanical degree of protection 1
Maintenance of vital functions in the crash of a military aircraft of the Starfighter type.

Thermal degree of protection 1
Maintenance of vital functions in the event of assumed kerosene releases and fires in the event of a crash of a military aircraft of at least the Starfighter type.

Mechanical degree of protection 2
Maintenance of vital functions with the load-time function according to the RSK Guidelines as well as a load-time function of a medium-sized commercial airliner.

Thermal degree of protection 2
Maintenance of vital functions in the event of assumed kerosene releases and fires upon the crash of a medium-sized commercial airliner.

Mechanical degree of protection 3
Design with the load-time function according to the RSK Guidelines as well as maintenance of vital functions with a load-time function of a large commercial airliner.

Thermal degree of protection 3
Maintenance of vital functions in the event of assumed kerosene releases and fires upon the crash of a large commercial airliner.

The review of the RSK showed that the requirements from the load assumptions according to the RSK Guidelines (crash of a fast-flying military aircraft of the Phantom type) are fulfilled for all plants that are still in operation. Due to the high basic protection of the plants still in operation, the RSK considered the fulfilment of degrees of protection 2 and 3 to be possible. For the confirmation of the fulfilment of degrees of protection 2 and 3 for the deliberate crash of a commercial airliner, further verifications were considered necessary.

Leak postulate

Within the framework of the safety review for the assessment of robustness with regard to possible cliff-edge effects, the RSK pointed out that, due to the design of the plants to withstand an aircraft crash with the load-time function according to the RSK Guidelines, no failure of coolant-retaining lines due to the impacts was and is assumed. Nevertheless, the RSK planned to additionally investigate the effects of a postulated rupture of a small pipe of the reactor coolant pressure boundary in terms of robustness and with regard to the potential for cliff-edge effects in case of an aircraft crash.

2 Current investigations

Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH was commissioned by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) to carry out investigations to determine whether, taking into account the failures and impairments to be expected as a result of the mechanical impacts and the kerosene fires, degree of protection 2 or degree of protection 3 according to the RSK safety review can be achieved for representative reference plants. These examinations are to determine the tolerability of the thermal and mechanical impacts as far as possible, using best-estimate calculations.

One reference plant each of the following types was selected:

- PWR Konvoi plant
- PWR pre-Konvoi plant and
- BWR construction line 72.

The calculations and assessments of the load cases for the individual plants are carried out one after the other in the order given.

In addition, the plant operators commissioned their own investigations by an engineering company experienced in this field and also investigated the effects of the postulated "Rupture of a small pipe (NB 50) in the reactor coolant system in the event of an aircraft crash with the load-time function according to the RSK Guidelines". This investigation was only carried out for pressurised water reactors (PWR) since in the case of the boiling water reactor (BWR) construction line 72 regarding the load case of an aircraft crash, only leaks in the containment system can lead to effects on the core and are therefore only to be postulated there. After rapid pressure suppression, coolant can then be injected from the pressure suppression pool.

An analysis was also carried out by the operators after what time fire-fighting measures can be expected on the plant site in the event of a crash of a commercial airliner.

At its 446th meeting on 5 April 2012, the RSK commissioned the ad hoc Working Group on AIRCRAFT CRASH (Ad-hoc-AG FLUGZEUGABSTURZ - AG FLAB) to accompany the analyses and to prepare a statement. The first partial report exclusively refers to the calculations and assessments regarding the Konvoi plants. The RSK adopted the associated statement at its 499th meeting on 6 December 2017. The present statement replaces the statement from the 499th RSK meeting and, in addition to the results for the Konvoi plants, also includes the analyses and assessments regarding the pre-Konvoi plants and the plant of BWR construction line 72. As with the first partial report, this final statement also includes the results of the operators' analyses insofar as, after evaluation of the operators' analyses, an independent analysis by experts was not considered necessary. This is shown in detail in the following chapters. The RSK discussed and adopted this statement at its 524th meeting on 20 October 2021.

3 Protection concept of the German nuclear power plants against aircraft crash

In the design of the nuclear power plants still in operation, the accidental crash of a fast-flying military aircraft of the "Phantom F4E" type was assumed and corresponding protective measures were taken by structural design or the physical separation of redundant equipment. The underlying load assumptions were included in the RSK Guidelines of 1979.

Following the events of 11 September 2001 in the USA when commercial airliners were used to deliberately attack buildings, the deliberate crash of a passenger aircraft with a terrorist background was also discussed. In a first study by GRS in 2002 on the "Protection of German nuclear power plants against the background of the terrorist attacks in the USA on 11 September 2001", aeronautical parameters and load assumptions were derived and the vulnerability to such an attack was assessed generically for all German nuclear power plants.

As a follow-up to the above-mentioned study, the operators developed a concept for countermeasures for all German nuclear power plants. In addition to an extension of the extinguishing possibility of kerosene fires by special foam fire-fighting vehicles, measures were planned in the plants which, after an alarm, aimed at establishing more favourable conditions for the control of such an event. These include, in particular, the triggering of reactor scram as well as the manning of the supplementary control room. These measures were implemented and taken into account for the investigations considered here.

After that, the Federal Ministry of the Interior and the Federal Ministry for the Environment issued a so-called RENEGADE Framework Plan NPP, which regulates the communication processes between the "Safety in Airspace" (ASt-SiLuRa) branch office of the Federal Police Headquarters and the nuclear power plants in the event of imminent danger i.a. from a deliberate aircraft crash. Part of this framework plan and the supplementary explanatory papers are, in addition to the definition of communication and alerting routes, the introduction of an alerting concept staggered into early warning and main alarm. With the binding implementation of this concept in the operating manuals/emergency manuals of all German nuclear power plants, comparable regulations exist in all plants that ensure the necessary internal alarms (e.g. plant fire brigade and standby teams), the staffing of the supplementary control room and the evacuation of plant areas in the event of an early warning and, in addition, reactor scram in the event of a main alarm.

Regarding protection against a deliberate crash of a passenger aircraft, not only has attention been paid to the resilience of potential targets against such events, but concrete measures have also been taken to prevent such attacks as far as possible.

It is thus a question of a combination of precautions

- which, on the one hand, make the hijacking of an aircraft and the targeted approach to a nuclear power plant more difficult, and

- which, on the other hand, lead to a high degree of resilience of NPPs to the effects of a deliberate crash.

The hijacking of a commercial airliner is made more difficult by technical and administrative measures to prevent terrorists from gaining access to the aircraft and especially to the cockpit. The international and national requirements for this have been updated several times since 2001 and security measures have been further strengthened worldwide. The regulations, measures and procedures relevant for Germany to protect against attacks on the security of air traffic, in particular against aircraft hijackings, acts of sabotage and terrorist attacks, are summarised in the National Aviation Security Programme (NLSP) (B3 643 213/1 of July 2010).

The design requirements for the German nuclear power plants still in operation were specified in the RSK Guidelines and were incorporated unchanged into the "Safety Requirements for Nuclear Power Plants" in 2012 with regard to the load case of an aircraft crash. The crash of a commercial airliner is neither part of these design requirements nor is it included in the load assumptions for protection against malicious acts (SEWD load assumptions).

At its meeting on 11 July 2016, the Länder Committee for Nuclear Energy - Main Committee - stated: "Since with regard to the scenario 'terrorist aircraft crash' - in contrast to the scenarios included in the SEWD load assumptions - no specific specifications were made in the SEWD rules and regulations with regard to the means of action to be postulated or not postulated (i.e. the aircraft type in this case), it is incumbent [...] on the respective competent authorities to define the scope of investigations for identifying measures that minimise or limit the radiation exposure in the event of an incident, taking into account the principle of proportionality. In principle, all aircraft types regularly used for passenger traffic are to be included in the consideration. However, according to the current state of knowledge, the Länder Committee for Nuclear Energy - Main Committee - assumes that, following the approach of the RSK, the Airbus A340-600 can generally be regarded as an exemplary aircraft type."

4 Definition of boundary conditions

In view of the lack of nationally and internationally established procedures for the investigation of deliberate terrorist attacks using commercial airliners, it was necessary for the RSK to define its own approaches for determining the effects, as explained below.

For this purpose, the data used in the GRS study on the "Protection of German nuclear power plants against the background of the terrorist attacks in the USA on 11 September 2001" were reviewed by the RSK ad hoc Working Group on AIRCRAFT CRASH (AG FLAB) and further data from aircraft manufacturers and airlines were consulted.

In the further course, the RSK ad hoc Working Group

- defined the reference velocity, the mass of the reference aircraft and the amount of kerosene, the hit position and the impact angle as well as the boundary conditions for system-related procedures and kerosene fires for the calculations regarding a deliberate aircraft crash,

- defined the concept for the analytical investigations of aspects in view of structural and systems design relating to such an aircraft crash.

For investigations with regard to the robustness of nuclear power plants against the (deliberate) crash of a passenger aircraft, assumptions must be made regarding characteristic values that are decisive for the resulting loads (e.g. aircraft type, associated derivable mass and velocity of the aircraft as well as kerosene volume). Since there is a wide spectrum of these parameters in aviation, it is appropriate to structure the investigations in such a way that the aircraft are divided into size classes, to each of which a representative aircraft is assigned.

Against this background, the RSK specifies the degrees of protection defined in its statement on the assessment of robustness after the accident at Fukushima with the following degrees:

Degree of protection 1
Loads resulting from the crash of a military aircraft of the Starfighter type (a Starfighter aircraft covers small aircraft types where access is not monitored, so government measures against hijacking are not effective).

Degree of protection 2
Loads resulting from the crash of a fast-flying military aircraft of the Phantom type as well as from a medium-sized commercial airliner in such a way that the selected reference aircraft covers approx. 90 % of the possible load impacts based on the assessment of the aircraft types and an evaluation of data on flight movements in scheduled and charter air traffic in European airspace. This class is represented by the Airbus A 320.

Degree of protection 3
Loads resulting from the crash of a large commercial airliner such that the selected reference aircraft covers approx. 99 % of the possible load impacts based on the assessment of aircraft types and an evaluation of data on flight movements in scheduled and charter air traffic in European airspace. This class is represented by the Airbus A 340-600.

When comparing the possible load impacts, the maximum take-off weights and the mass distribution of the aircraft types were taken into account, among other things.

The evaluation of aircraft movements in European airspace was carried out by GRS for a period of 12 months prior to the coronavirus pandemic on the basis of data from a publication by EUROCONTROL EXPERIMENTAL CENTER.

Within the scope of the RSK robustness assessments newly performed here, degree of protection 1 as well as degree of protection 2/Phantom type are no longer dealt with, since for the nuclear power plants still in operation, the design during construction already covers the corresponding scenarios, see RSK Safety Review 2011 (Statement from the 437th RSK meeting from 11 to 14 May 2011). Therefore, the investigations were limited to the representative commercial aircraft types A 320 and A 340. The attacks on the World Trade Center and the Pentagon in 2001 were carried out with commercial aircraft (B 767 and B 757) that rank between the types A 320 and A 340 in size and weight.

Other aircraft, such as the A 380, as well as special military or civil aircraft (e.g. Antonov An-225) were not investigated as load cases as the number of associated aircraft movements is significantly lower (less than 0.5 %) than the number of aircraft movements covered by the reference aircraft. Furthermore, a consideration of the load-determining characteristics shows that larger aircraft do not necessarily lead to more adverse impacts.

Due to the higher maximum take-off weight, a higher damage effect is occasionally assumed for the A 380 compared to the A 340-600, which was examined in detail. However, this assumption does not take into account the following opposing aspects:

- For the local structural integrity, the occurring area load is particularly relevant. For the main structures, this is not higher for the A 380 than for the A 340-600.

- The greater maximum take-off weight of the A 380 results primarily from a significantly higher maximum amount of fuel in the wings. However, due to the larger wingspan compared to the diameter of a reactor building, the impulse of the wings with the fuel cannot be completely transferred to the concrete shell.

With regard to the selection of the aircraft types to be considered, the RSK is of the opinion that the spectrum of fast-flying, jet-powered commercial airliners flown in European airspace is sufficiently covered by the selection of corresponding reference aircraft as described above. With a coverage of about 95 % of the possible load impacts, the reference aircraft used provide a sufficient basis for an assessment of the robustness of the NPPs.

As impact velocity, the velocity was assumed that was also used in the GRS study on the "Protection of German nuclear power plants against the background of the terrorist attacks in the USA on 11 September" and which, within the scope of this robustness analysis and after further research by GRS, is considered by the RSK as representative of a still controllable approach at the required low altitude. When determining the velocity, general flight conditions as well as the results from simulator tests and interviews with pilots were taken into account.

A loading situation of the aircraft was taken as a basis, both in terms of total weight and fuel quantity, which covers a large part (95 %) of the real flight movements of the respective reference aircraft type in Germany. For this purpose, GRS evaluated the flight movements of the representative aircraft types in Germany for a period of 12 months before the coronavirus pandemic.

When determining the impact location, possible approach scenarios were considered (approach not disturbed by obstacles) and an area of the reactor building was selected where adverse effects are to be expected due to the structural and geometric conditions.

With regard to the fire scenarios, the location where the most adverse effects occur was chosen, taking into account that the kerosene can also reach there when the aircraft crashes. A conservatively high burn-up rate was taken into account which leads to the complete burning of the kerosene pool before any possible fire-fighting measures are initiated. In addition, it was considered whether fire effects on canals or other buildings could lead to failures that could result in cliff-edge effects.

The entirety of the boundary conditions applied represents a determination that defines a resulting load in the upper range of loads from the possible combinations of parameter values but does not assign the most adverse possible value to each individual parameter.

5 Methodology of the investigations and assessments

Taking into account the boundary conditions mentioned in the previous chapters, the following steps were chosen for the computational determination of the effects of a deliberate aircraft crash:

- determination of the structures that must sufficiently withstand a deliberate aircraft crash in order to avoid a cliff-edge effect in the radiological consequences for the surrounding area,
- modelling of these structures and the aircraft representative of degree of protection 2 and 3, respectively, in order to quantify the mechanical effects on the shell and the internal structures of the buildings as well as the induced vibrations with coupled FEM calculations,
- investigation of the capacity of the components, including supports and building connections, that are relevant for the control of the event to transfer the loads occurring as a result of the induced vibrations.

5.1 Structures to be investigated in detail

The concept of the plants for protection against an (accidental) crash of a fast-flying military aircraft of the Phantom type provides that such events are controlled with the equipment that

- in the PWR is located in the reactor building, in the emergency feedwater building and in ducts protected by covers and by physical separation, as well as in physically separated intake structures
- in the BWR is located in the reactor building, in physically separated structures, each with a sufficient number of emergency diesel generators, in ducts protected by covers and physical separation, and in physically separated intake structures.

However, the investigations of the mechanical and thermal impacts of the deliberate crash of a commercial airliner can be limited to the reactor building for the following reasons:

- The reactor building contains the fuel elements, the radioactive inventory of which is not to be released.
- In the case of the PWR, an approach to the emergency feedwater building would be difficult due to its low height above ground. The impact could at best occur at a shallow angle on the building roof, which would not lead to any relevant damage to the emergency feedwater building. A large-scale fire due to the large amounts of kerosene could lead to a shut-off of the physically separated intakes for the emergency diesel by means of fire dampers. However, due to the design of the building, it is not assumed that the function of the secured part of the reactor protection system, which is also located in the emergency feedwater building, would be impaired in the event of such an external hazard. Under

these boundary conditions, the switchgear building with the control room, the turbine building and the emergency diesel building would remain unaffected, as these buildings are sufficiently remote. From there, the feeding of the steam generators could therefore be secured, by using e.g. the start-up and shut-down system in the turbine building or by emergency measures, as could be the release of steam for heat removal.

- In the case of the BWR 72, the emergency power supply required for cooling the pressure suppression pool and for return feeding from the pressure suppression pool into the RPV can be ensured by means of emergency power diesels housed in different buildings that are physically separated in such a way that they cannot fail at the same time even in the event of the crash of a commercial airliner. The emergency power busbars can be coupled with each other and with the emergency power supplies of the other unit. In addition, further diesels of the additional independent residual-heat removal system (ZUNA) are available which, due to their physical separation, will remain unaffected in the event of a hit of the emergency power supply equipment.

- In the event of an impact in the area of the intake structures, cross-redundancy damage would not be assumed due to their physically separate arrangement. Furthermore, even in the event of a direct hit on part of the intake structures, significant parts of the plant would not be affected.

- Similarly, the ducts located in the ground are also protected against the effects of debris by being covered with earth and, in some cases, with reinforced concrete slabs. Where this is not the case (in the case of some individual plants, there is no division of the return flow of the secured auxiliary service water into redundant pipes/routes), heat removal can be established sufficiently quickly via existing emergency measures (diverse heat sink) if necessary.

Overall, it is therefore only the scenario with an impact on the reactor building that is relevant for the considerations.

5.2 Modelling of reactor building and aircraft

The analyses of the behaviour of the civil structures and engineered systems were largely carried out using best-estimate methods. The influence of the scatter of individual essential parameters was taken into account.

The authorised experts' computational analyses of the behaviour of the structures were carried out using the ABAQUS/Explicit software, which allows elastic and elasto-plastic deformations to be determined and complex non-linear material models to be taken into account for highly dynamic loads. With this software, both the reactor building and the impacting aircraft were represented by detailed finite-element (FE) models. Both models were coupled for the calculation in order to directly determine the structural response upon impact of the aircraft in an overall model. The models were compared with the manufacturers' data for the reactor building and the aircraft.

The reactor building model is based on civil engineering documents provided by the operator.

The outer shell of the reactor building (shield building) was modelled in detail with volume elements for the concrete and considering the reinforcement. In the area of the point of impact, a finer mesh with an increased number of volume elements over the wall thickness was chosen than away from the impact area. The tensile and shear reinforcement was explicitly modelled with bar elements in the impact area. The bar elements of the reinforcement were rigidly coupled to the nodes of the concrete structure in the model.

In the building model of the PWR, the main building structures in the annulus are taken into account. These are all building structures including the topmost solid ceiling with a thickness of 60 cm. The effect of the expansion joint (so-called external hazard joint) between the reactor building wall and the face of this ceiling was modelled non-linearly. After the joint is closed by the local displacement of the reactor building, the ceiling behind it acts as an abutment, which on the one hand supports the reactor building wall, but on the other hand leads to an increased input of induced vibrations into the annulus structures. The primary circuit and other heavy mechanical components were not explicitly represented in the model. Instead, the masses of these components are added locally to the building mass.

For the BWR, the main building structures of the outer cylinder with base plate and roof as well as the inner structures up to approx. +40.5 m were considered. The inner structures are separated from the outer cylinder by a joint with a width of 15 cm (for the platforms at the biological shield 10 cm). The end wall of the spent fuel pool and the adjacent platforms have been modelled in detail. The water-steam cycle and other heavy mechanical components were not explicitly modelled in the model, but the masses of these components were added locally to the mass of the structure. The reactor pressure vessel including the support skirt was modelled as a beam oscillator. Furthermore, the springs and dampers (GERB vibration absorbers) to protect the two control units for operation and monitoring in case of specific external hazards (in German: Teilsteuerstelle - TEST) from induced vibrations are explicitly taken into account in the model.

The massive floor slabs of the reactor buildings (both PWR and BWR) are represented in the FE model as a rigid slab that is coupled to the subsoil via spring and damper assemblies.

In the structural calculations, material parameters were used for the concrete and the reinforcement which, according to engineering experience, give a description of the structural behaviour that is as close to reality as possible.

The modelling approaches and the material models for the reactor building have been validated as far as possible using experiments documented in the technical literature.

In the aircraft model, the effect of the kerosene was represented in such a way that the mass of the kerosene was added to the masses of the associated structural components of the aircraft. This is a conservative approach with regard to the expected loads on the reactor building.

The results of the coupled best-estimate calculations for the load-time function were checked and confirmed by comparison with the results of recognised simplified methods (Riera method).

With the coupled model described above, in addition to the global stability and the displacement of the reactor building, the local deformations and damage of the building wall in the impact area (in particular the deflection of the outer building shell of the reactor building) as well as the induced vibrations (floor response spectra) were calculated at positions in the building where safety-relevant components and building structures required for vital functions are located.

In the coupled analyses carried out by an engineering company in parallel and independently on behalf of the operators, the LS-Dyna program was used. In some cases, different modelling approaches and material parameters were used. The comparison with the results of these calculations allowed an additional assessment of the effects of model uncertainties on the calculation results. In this way, for example, it was possible to assess the influence of different model meshes (volume versus shell elements), structural damping and dynamic strength increases.

5.3 Systems engineering assessment with regard to induced vibrations

The impact when the aircraft hits the outer shell of the reactor building leads to induced vibrations inside the building. The model of the reactor building described above was used to calculate the transmission of the vibrations. This model was used to calculate the acceleration spectra or the acceleration time histories and the displacements at the attachment points of those mechanical components ("floor response spectra") that are relevant for ensuring the vital process engineering functions.

The assessment of whether these components retain their integrity and, if necessary, their functionality despite the stresses that occur was carried out in a multi-stage process:

a) In a first step, the determined spectra were compared with the spectra or load assumptions for earthquake and aircraft crash used for the original design of the respective components. Where the new spectra resulted in lower loads than in the design, this meant that the assessment could be concluded positively.

b) Where the new spectra resulted in higher loads than those used in the design (e.g. for higher frequencies in the spectrum compared to the original aircraft crash load case), the displacement to be expected at the component was considered. For displacements < 1 mm, the assessment could also be concluded positively, since such small displacements certainly do not lead to any damage due to the tolerance in the mounts as well as the elasticity in the components.

c) If a) and b) could not be confirmed, the design and installation documents of the corresponding components were used for the examination. A positive assessment was possible in individual cases if higher loads were covered by the construction of the component than resulted from the currently determined spectra (e.g. greater loads from other load cases such as a loss-of-coolant accident, large safety margins in the permissible maximum stress ratio for this load case, greater verified accelerations on a vibration table).

d) If a) - c) do not allow a positive assessment, it is possible to recalculate the load transfer in the components, e.g. using FE methods. This was used for the assessment of individual structures and components (e.g. flooding tanks in the Konvoi plants and in one pre-Konvoi plant).

e) If credit has been taken of safety margins in the strength of components in considerations according to d), it has also been assessed whether safety margins for the correspondingly increased load transfer are given for the affected building connections.

In the determination of the loads on components, supports and building connections that occur as a result of induced vibration, the building connections were assumed to be rigid and linear-elastic calculation methods were used. This leads to an overestimation of the actual loads. A quantification of the further margins given with this would require elaborate investigations, which were not necessary with the available results.

6 Results regarding Konvoi plants

In the case of the Konvoi plants, the assumed scenario (impact of the aircraft shortly after reactor scram/turbine trip and start of partial shutdown and boration) can be controlled by automatic reactor coolant system isolation, by one process-engineered redundant system train each for the required heat removal (initially via the secondary side, after > 10 hours via an emergency core cooling and residual-heat removal chain) as well as by a redundant system train of the extra borating system with intake from the extra borating tank and the flooding tanks for ensuring long-term subcriticality. The operation and monitoring of the above-mentioned process-engineered equipment is ensured by the secured instrumentation and control system and the supplementary control room personnel in the emergency feedwater building, the electrical power supply is ensured by the uninterruptible power supply and the D2 grid with the emergency diesels supplying the emergency feedwater system.

6.1 Results regarding degree of protection 2

- **Behaviour of the outer reactor building wall in the area of the point of impact**
  There will be neither any wall penetration of the reactor building (outer building shell) by aircraft structures nor any displacements of the concrete structures that can bridge the joint between the outer building wall and the inner building structures. An entry of kerosene into the reactor building is therefore excluded.

- **Global stability of the building and building displacements**
  The global stability of the building is not in question. A covering assessment of the controllability of any resulting building displacements was carried out for degree of protection 3, see below.

- **Induced vibrations, effects**
  In the case of the induced vibrations, the design values for the acceleration of components are consistently undercut in the lower frequency range (comparable with the frequencies caused by earthquakes); in the upper frequency range, there are individual minor exceedances of the accelerations on which the design against aircraft crash is based, which, however, cannot cause any danger to components due to the low vibration amplitudes observed.

- **Fire impacts**
  The effects of an external fire will neither endanger building structures nor the systems and electrical equipment necessary to control the event. This was not explicitly considered for the aircraft category associated with degree of protection 2 but was derived from the covering analyses for degree of protection 3.

6.2 Results regarding degree of protection 3

- **Behaviour of the outer reactor building wall in the area of the point of impact**
  There will be no wall penetration of the reactor building (outer building shell) by aircraft structures. An entry of kerosene into the reactor building can therefore be excluded. The maximum displacement of the concrete structures will cause the joint between the outer building wall and the inner building structures to be locally bridged, resulting in a partial impact transfer to the inner structures (ceilings and walls in the annulus) on the one hand, and a supporting effect for the outer building wall on the other. This may lead to local damage at the point of contact, but not to a failure of the inner building structures. No impact transfer to the containment was found.

- **Global stability of the building and building displacements**
  The global stability of the building is not in question. For large parts of the building, the loads even remain at values that are elastically transferred. Furthermore, the maximum displacements of the reactor building are so small that the integrity and functionality of the piping or cable routes leading through the outer wall are not endangered.

- **Induced vibrations, effects**
  In the case of the induced vibrations in the areas of the building that are remote from the point of impact (containment and the components located in the annulus in the lower area), in the lower frequency range (comparable to the frequencies caused by an earthquake), the design values of the accelerations for the equipment that is safety-relevant and which accordingly is designed to withstand external hazards are consistently undercut. In the upper frequency range, the accelerations on which the design against aircraft crash is based are exceeded, but with the low vibration amplitudes found, this cannot cause any danger to components.

  Where credit has been taken here of the design margins of components, it has also been checked that sufficient margins can also be applied to the affected supports and building connections.

  Due to the bridging of the gap between the outer and inner building structures during the load impact, the induced vibrations in the annulus at the height of the point of impact were examined in more detail for this load case with regard to their effects on safety-relevant components. The result shows that the accelerations on which the design against aircraft crash is based are only exceeded in the upper frequency range. With regard to the vital functions, it was possible to prove that the required number of components in the redundant system trains located at a distance from the point of impact remain functional. With regard to components with flooding potential in the event of failure, proof of their integrity was also provided in the area close to the point of impact.

For the equipment not designed to withstand external hazards (e.g. parts of the demineralised-water system), a general assumption was made that there would be a loss of integrity, particularly in water-bearing pipes and tanks, and that, in addition, the emergency-proof interlocks provided for automatic isolation would not become effective. The analysis shows that even with the maximum amount of water to be assumed in the annulus, there will be no flooding of components required for vital functions and these will thus retain their functionality, provided that 2 hours after the impact, measures against a further level rise have been e implemented as described in the operating documents.

A detachment of the building crane from the crane runway due to induced vibrations with a resulting fall and consequential damage need not be assumed for the PWR. The crane runway is mounted on top of the missile protection wall inside the containment. Due to the arrangement of the missile protection wall, vibrations are only induced indirectly via the foundation plate, so that the amplitudes remain relatively low. In addition, the building crane is always in a defined parking position, where horizontal displacement is limited by buffers. With regard to vibrations induced by external hazards, the crane trolleys are secured against jumping off by clamps.

- **Fire impacts**
  The effects of an external fire will neither endanger building structures nor the systems and electrical equipment necessary to control this event. In the event of a kerosene pool burning below the valve chamber, the components are protected by the building structures. Possible larger penetrations such as the pressure relief dampers will not open under the induced loads to be assumed. The design of the pressure relief dampers in fire resistance class F-90 ensures that there will be no unacceptable temperatures for components in the valve chamber that are required for vital functions.

6.3 Applicability of results from the reference plant to other Konvoi plants

The Konvoi plants are so similar in their design requirements and designs of the components and structures as well as the spatial arrangement of the relevant structures that the analysis results for the reference plant can be applied to the other two plants without further detailed considerations.

6.4 Results regarding the reactor coolant pressure boundary leakage postulate

The plants under consideration have been designed in such a way that the integrity of the reactor coolant pressure boundary is ensured even in the case of accelerations that may occur during design basis earthquakes or during the postulated crash of a fast-flying military aircraft of the Phantom type (load-time function according to the RSK Guideline or the "Safety Requirements for Nuclear Power Plants") as a result of induced vibrations. Therefore, a loss of coolant due to a leak is not assumed for these events by design. Despite the design of the piping of the reactor coolant pressure boundary to withstand loads from the aircraft crash according to the RSK Guidelines, the RSK had included in its work programme to postulate the rupture of a small pipe in this area for the crash of a fast-flying military aircraft of the Phantom type to be assumed according to design and to investigate the possible effects.

Due to the above-mentioned safety margins in the design of the plants, it is not to be expected that a leak with a loss of coolant will occur as a result of induced vibrations, even in the event of an impact of a commercial airliner corresponding to degree of protection 2 or 3 with increased accelerations in higher frequency ranges. A combination of two beyond-design-basis postulates (crash of a commercial airliner and rupture of a connection line to the reactor coolant pressure boundary) was not considered.

The RSK has specified the following boundary conditions for the investigation:

- leakage rate corresponding to an NB 50 leak when a connection line ruptures at the most unfavourable point of the reactor coolant pressure boundary,
- technically qualified personnel available such that credit can be taken of manual operation after 2 hours,
- crediting only of equipment and systems that are protected by structural measures, physical separation or design to withstand the effects of an aircraft impacting the reactor building,
- investigation of the event sequence with shutdown of the plant to a state in which the reactor coolant pressure boundary leak can be overfilled with the help of the emergency residual-heat removal pumps in sump operation mode in the case of a subcritical plant.

For this purpose, a study was submitted by the operators with the following covering assumptions: unavailability of the auxiliary power supply as well as of the D1 grid and thus of the operational feedwater supply, the volume control system and the pumps of the emergency core cooling and residual-heat removal system, with the following results:

- Due to the assumed small leak, fast secondary-side shutdown (100 K/h) is triggered automatically. The level in the steam generators is maintained by the emergency feedwater system.
- With the initial rapid pressure drop and the further lowering of the pressure in the primary system caused by the secondary-side shutdown, the leakage rate continuously decreases so that the level in the primary system can be kept above the upper edge of the core first with the injection via the hot-leg pressure accumulators and then, in the longer run (after just under 2 hours), by the extra borating system. In this constellation, secondary-side heat removal and a covering of the core with coolant would be ensured for more than 10 hours even if no measures by the plant personnel are taken into account during this time. As the supplementary control room is manned, these measures could also be carried out after approx. 2 hours.
- Hence there is sufficient time for the plant personnel to switch on the emergency core cooling and residual-heat removal system, thus refilling the primary system and switching over to primary-side heat removal.

The RSK concludes that these results show that a scenario of an aircraft crash with the load-time function according to the RSK Guidelines (crash of a fast-flying military aircraft of the Phantom type) with an additionally assumed small leakage due to the rupture of a connection line at the primary system will not result in any cliff-edge effects and can be controlled.

7 Results regarding pre-Konvoi plants

In the case of the pre-Konvoi plants, the assumed scenario (impact of the aircraft shortly after reactor scram/turbine trip and start of partial shutdown and boration) can be controlled by automatic reactor coolant system isolation, by one process-engineered redundant system train each for the required heat removal (initially via the secondary side, after > 10 hours via an emergency core cooling and residual-heat removal chain) as well as by a redundant system train of the extra borating system with intake from the extra borating tank and a pair of flooding tanks for ensuring long-term subcriticality. The operation and monitoring of the above-mentioned process-engineered equipment is ensured by the secured instrumentation and control system and the supplementary control room personnel in the emergency feedwater building, the electrical power supply is ensured by the uninterruptible power supply and the D2 grid with the emergency diesels supplying the emergency feedwater system.

7.1 Results regarding degree of protection 2

- **Behaviour of the outer reactor building wall in the area of the point of impact**
  There will be neither any wall penetration of the reactor building (outer building shell) by aircraft structures nor any displacements of the concrete structures that can bridge the joint between the outer building wall and the inner building structures. An entry of kerosene into the reactor building is therefore excluded.

- **Global stability of the building and building displacements**
  The global stability of the building is not in question. A covering assessment of the controllability of any resulting building displacements was carried out for degree of protection 3, see below.

- **Induced vibrations, effects**
  For the relevant components, it could be shown that, as a rule, the determined response spectra for the installation points were covered by the earthquake design spectra or by the design spectra for aircraft crash (according to the RSK Guidelines) or that they complied with the 1-mm criterion for the displacements. At some higher points in the containment, the 1-mm criterion was exceeded. However, an individual assessment of the design margins of the affected components showed that a failure of the components was not to be assumed.

- **Fire impacts**
  The effects of an external fire will neither endanger building structures nor the systems and electrical equipment necessary to control the event. This was not explicitly considered for the aircraft category associated with degree of protection 2 but was derived from the covering analyses for degree of protection 3.

7.2 Results regarding degree of protection 3

- **Behaviour of the outer reactor building wall in the area of the point of impact**
  There will be no wall penetration of the reactor building (outer building shell) by aircraft structures. An entry of kerosene into the reactor building can therefore be excluded. The maximum displacement of the concrete structures will cause the joint between the outer building wall and the inner building structures to be locally bridged, resulting in a partial impact transfer to the inner structures (ceilings and walls in the annulus) on the one hand and a supporting effect for the outer building wall on the other. This may lead to local damage at the point of contact, but not to a failure of the inner building structures. An impact transfer to the containment was determined, but only slight local plastic deformations occurred, which do not call the integrity into question.

- **Global stability of the building and building displacements**
  The global stability of the building is not in question. For large parts of the building, the loads even remain at values that are elastically transferred. Furthermore, the maximum displacements of the reactor building are so small that the integrity and functionality of the piping or cable routes leading through the outer wall are not endangered.

- **Induced vibrations, effects**
  For the induced vibrations in the building areas remote from the point of impact (containment and the components located in the annulus in the lower area), the determined response spectra for the installation points of the equipment that is important for safety and therefore designed to withstand external hazards are largely covered by the - very conservatively calculated - design spectra for aircraft crash (according to the RSK Guidelines). As far as this is not the case for higher frequencies, it could be shown that, as a rule, the 1-mm criterion is met. In the case of individual exceedances of this criterion, it could be shown that the corresponding loads are transferred due to existing design margins in components, brackets and structural connections in such a way that their integrity and, if necessary, function continue to be ensured.

  Where credit has been taken here of the design margins of components, it has also been checked that sufficient margins can also be applied to the affected supports and building connections.

  Due to the bridging of the gap between the outer and inner building structures during the load impact, the induced vibrations in the annulus at the height of the point of impact were examined in more detail for this load case with regard to their effects on safety-relevant components. The result shows that the accelerations on which the design against aircraft crash is based are only exceeded in the upper frequency range. With regard to the vital functions, it was possible to prove that the required number of components in the redundant system trains located at a distance from the point of impact remain functional. With regard to components with flooding potential in the event of failure, proof of their integrity was also provided in the area close to the point of impact.

  For the equipment not designed to withstand external hazards (e.g. parts of the demineralised-water system), a general assumption was made that there would be a loss of integrity, particularly in water-bearing pipes and tanks, and that, in addition, the emergency-proof interlocks provided for automatic isolation would not become effective. The analysis shows that even with the maximum amount of water to be assumed in the annulus, there will be no flooding of components required for vital functions and these will thus retain their functionality, provided that 2 hours after the impact, measures against a further level rise have been implemented as described in the operating documents.

A detachment of the building crane from the crane runway due to induced vibrations with a resulting fall and consequential damage need not be assumed for the PWR. The crane runway is mounted on top of the missile protection wall inside the containment. Due to the arrangement of the missile protection wall, vibrations are only induced indirectly via the foundation plate, so that the amplitudes remain relatively low. In addition, the building crane is always in a defined parking position, where horizontal displacement is limited by buffers. With regard to vibrations induced by external hazards, the crane trolleys are secured against jumping off by clamps.

- **Fire impacts**
  The effects of an external fire will neither endanger building structures nor the systems and electrical equipment necessary to control this event. In the event of a kerosene pool burning below the valve chamber, the components are protected by the building structures. Possible larger penetrations such as the pressure relief dampers will not open under the induced loads to be assumed. The design of the pressure relief dampers in fire resistance class F-90 ensures that there will be no unacceptable temperatures for components in the valve chamber that are required for vital functions.

7.3 Applicability of results from the reference plant to other pre-Konvoi plants

In essence, the differences between the reference plant and the other pre-Konvoi plants which could possibly lead to more adverse impacts are limited to the following points in the case of one other plant:

- pile foundation instead of raft foundation
- flooding pool instead of flooding tank
- the valve chamber is not shielded from an approaching aircraft by other structures.

Specific considerations of the operator on these points led to the following conclusions:

- **Pile foundation**
  Analyses with a dynamic calculation model taking into account the pile-soil-pile interaction for degree of protection 3 showed that the foundation piles transfer the loads within the design and, in addition, the induced vibrations in the reactor building tend to be less due to a somewhat "softer behaviour".

- **Flooding pools**
  With a non-linear calculation, it was shown for the displacements in the reactor building to be expected with loads corresponding to degree of protection 3 that the lining of the flooding pools will remain intact. A leakage from the lined pools is therefore not to be expected.

- **Valve chamber**
  Structural calculations and considerations of the effects of a hit on the valve chamber by an aircraft according to degree of protection 3 and an impact position assessed as unfavourable showed that at least

one main steam safety valve and the emergency feedwater supply remained functional and at least one main steam isolation valve closed. Thermal-hydraulic accident analyses showed for degree of protection 3 that the plant can be transferred to a safe state with the remaining systems. Otherwise, the results of the reference plant can be applied.

7.4 Results regarding the reactor coolant pressure boundary leakage postulate

A thermohydraulic analysis showed that despite certain system-related differences (e.g. smaller inventory of borated-water storage tanks compared to Konvoi plants), the plant can be transferred to a controlled state (subcritical, cold, depressurised) in the scenario of a postulated small leak in a similar way to Konvoi plants.

8 Results regarding the boiling water reactor construction line 72

In the case of the BWR construction line 72, due to the 3 x 100% design of the residual-heat removal system (plus 1 x 100% additional independent residual heat removal system (ZUNA)), one functional redundancy or the ZUNA system is sufficient to control the event. One of the two control units for operation and monitoring in case of specific external hazards (TEST) including the equipment of the associated redundant system train has to remain available for the performance of the basic safety functions. Furthermore, the integrity of systems and components with a potential for flooding must be ensured.

8.1 Results regarding degree of protection 2

- **Behaviour of the outer reactor building wall in the area of the point of impact**
  There will be neither any wall penetration of the reactor building (outer building shell) by aircraft structures nor any displacements of the concrete structures that can bridge the joint between the outer building wall and the inner building structures. An entry of kerosene into the reactor building is therefore excluded.

- **Global stability of the building and building displacements**
  The global stability of the building is not in question. A covering assessment of the controllability of any resulting building displacements was carried out for degree of protection 3, see below.

- **Induced vibrations, effects**
  In the case of the induced vibrations, in the lower frequency range (comparable to the frequencies excited during an earthquake), the design values for the acceleration of components are undercut for the majority of the safety-relevant components. In the middle and upper frequency range, there are several exceedances of the accelerations on which the design against aircraft crash (according to the RSK Guidelines) is based. Due to the low vibration amplitudes determined and taking into account the design margins, this will not result in any danger to components. Where credit has been taken here of the design margins of components, it has also been checked that sufficient margins can also be applied to the affected supports and building connections. As the control units for operation and monitoring in case of

specific external hazards (TEST) located in the reactor building are protected against induced vibrations by springs and dampers (GERB vibration absorbers), no accelerations will occur there that are not covered by the design.

- **Fire impacts**
  The effects of an external fire will neither endanger building structures nor the systems and electrical equipment necessary to control the event. This was not explicitly considered for the aircraft category associated with degree of protection 2 but was derived from the covering analyses for degree of protection 3.

8.2 Results regarding degree of protection 3

- **Behaviour of the outer reactor building wall in the area of the point of impact**
  There will be no wall penetration of the reactor building (outer building shell) by aircraft structures. An entry of kerosene into the reactor building can therefore be excluded. The maximum displacement of the concrete structures will lead to local bridging of the joint between the outer building wall and the inner building structures. This will lead to local damage at the contact point but not to a failure of the internal building structures. In case of closure of the joint, a maximum displacement of the wall of the spent fuel pool of less than 10 cm will occur. No damage will occur that will lead to a leakage from the spent fuel pool. The spent fuel pool will remain intact.

- **Global stability of the building and building displacements**
  The global stability of the building is not in question. For large parts of the building, the loads even remain at values that are elastically transferred. Furthermore, the maximum displacements of the reactor building are so small that the integrity and functionality of the piping or cable routes leading through the outer wall are not endangered.

- **Induced vibrations, effects**
  For the reference plant of BWR construction line 72, the input of induced vibrations after closing of the joint mainly acts directly on the inner area.

  In the case of the induced vibrations in the building areas remote from the point of impact, in the lower frequency range (comparable to the frequencies excited during an earthquake), the design values of the accelerations for the equipment that is safety-relevant and is therefore designed against external hazards are only partially undercut. For the remaining components, component verifications were therefore used to determine the design margins. The exceeding of the acceleration limits in the upper frequency range, which are the basis for the design against aircraft crash, do not result in any danger to components due to the low vibration amplitudes determined or with consideration of the design margins. Where credit has been taken here of the design margins of components, it has also been checked that sufficient margins can also be applied to the affected supports and building connections.

  As the control units for operation and monitoring in case of specific external hazards (TEST) located in the reactor building are protected against induced vibrations by springs and dampers (GERB vibration absorbers), no accelerations will occur there that are not covered by the design.

With regard to the vital functions, it was possible to prove that the required number of components in the redundant system trains located at a distance from the point of impact remain functional. With regard to components with flooding potential in the event of failure, proof of their integrity in the area close to the point of impact was also provided.

The water-bearing pipes and associated components that are not designed to withstand external hazards and whose failure has the potential to cause flooding have either been explicitly included in the analysis of the effects of induced vibrations or their failure cannot lead to leakages requiring countermeasures in the short term. Larger tanks whose loss of integrity could lead to flooding and a subsequent failure of vital functions do not exist in the BWR construction line 72.

The building crane is redundantly secured by brackets so that a fall can be ruled out.

- **Fire impacts**
  The effects of an external fire will not endanger building structures. There are no openings in the reactor building, and the connecting ducts between the reactor building and the emergency power buildings and the purified-water lines are protected by earth cover.

9 Conclusion

The RSK has concluded its consultations on the deliberate aircraft crash with the present statement. The RSK concludes:

The entirety of the boundary conditions used represents a determination that defines a resulting load in the upper range of loads from the possible combinations of parameter values but does not assign the most unfavourable value possible to each individual parameter.

The fulfilment of the requirements of degrees of protection 2 and 3 (cf. Chapter 4) could be demonstrated. The vital functions for controlling the events are maintained to the required extent. No indications of any cliff edge effects were found for any of the hazards considered.

It has thus been demonstrated that even in the event of a deliberate crash of a large commercial airliner onto the plants under consideration (pre-Konvoi commissioned in 1984 or later, Konvoi and BWR construction line 72), the cooling of the fuel assemblies in the reactor and in the spent fuel pool will be maintained so that releases of radioactive substances from spent fuel damage are not to be expected.

It has also been shown that a scenario of an aircraft crash with the load-time function according to the RSK Guidelines (crash of a fast-flying military aircraft of the Phantom type) with an additionally assumed small leak due to the rupture of a connecting line to the reactor coolant system will not result in any cliff-edge effects and will be controlled.