Note:
This is a translation of the RSK Statement entitled
"Zwischen- und Nebenkühlwassersysteme"
In case of discrepancies between the English translation and the German original, the original shall prevail.

RSK Statement
(513th meeting of the Reactor Safety Commission (RSK) on 11 December 2019)

Closed cooling water and service water systems

STATEMENT

Table of contents

1 Introduction

This Statement deals with two aspects. On the one hand, it considers the advisory request by the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) of 27 March 2015 (file reference: RS I 3 – 1 7018/ 1 [1]) in which the RSK was requested to prepare a statement on the requirements for the closed cooling water and service water systems for residual-heat removal. The following questions are to be answered for plants that are still in power operation:

- Are the existing regulatory requirements and/or the basic approach to the design and monitoring of the systems sufficient to ensure that the systems currently available in the plants can be operated with sufficient safety margins with regard to the aspects 'operational monitoring' and 'load spectrum to be considered' and that thus the higher-level requirements specified in the RSK Guidelines and the Safety Requirements are fulfilled?

- With regard to these two aspects, is there a need to formulate additional requirements, and if so, which ones?

The other aspect deals with questions in connection with the robustness of nuclear power plants in earthquakes.

In the plant-specific safety review (RSK-SÜ) [2] it was determined that, with regard to the seismic design of the German nuclear power plants, considerable safety margins exist in part. This assessment is based, among other things, on the conservativeness contained in the calculation chain and on the knowledge on the seismic PSAs performed for individual plants so far. The RSK sees the potential for safety margins to the amount of one intensity level.

After conclusion of the RSK-SÜ, the question arose whether the classification of robustness was valid, considering the fact that as concerns the pressurised water reactor (PWR) plants of the Konvoi type, downgraded requirements were made in the licensing procedure for the redundant low-energy systems (low pressures and temperatures) of the closed cooling water and service water systems as part of the emergency core cooling and residual-heat removal systems, and that application of the Generic Specification on Basic Safety of Pressure retaining Components [7] was not required. Thus, the question arises whether in terms of plant robustness – e.g. in case of a seismic impact of an intensity level above the earthquake determined plant-specifically according to the state of the art in science and technology, basis: exceedance probability of 10^{-5}/a – sufficient safety margins also exist for those systems of the Konvoi plants for which the requirements of the Generic Specification on Basic Safety were not fully applied during design and manufacture.

The question of robustness can also be applied to the only plant of the boiling water reactor (BWR) construction line 72 that is still in power operation; in this case, the requirements of the Generic Specification on Basic Safety were also not implemented in the design of the closed cooling water and service water systems.

2 Safety significance

The systems provided for emergency core cooling and primary-side residual-heat removal (RHR) during design basis accidents are part of the safety system of the reactor plant. Using the system designations of the Konvoi plants, these are the nuclear residual-heat removal systems JN, the nuclear closed cooling water system for safety-relevant equipment KAA, and the service water system for essential installations PE. For the cooling of the emergency diesel generators of the D1 emergency power grid, the closed cooling water system (secured plant) PJ is additionally required. Furthermore, the spent fuel pool cooling pumps of the FAK10 and FAK40 pipe sections serve as emergency residual-heat removal pumps in case of an emergency. For the pre-Konvoi plants KBR and KWG as well as the plants of BWR construction line 72, the corresponding systems are referred to as nuclear residual-heat removal systems TH, nuclear closed cooling water system TF, and nuclear service water systems VE. Their safety-related tasks are to remove residual heat when the plant is shut down and in the case of design basis accidents with and without loss of coolant and – in the case of the BWR – to cool the pressure suppression pool. In addition, drywell spraying and drywell flooding after loss-of-coolant accidents are possible in BWRs.

Against this background, the function of the systems must be ensured, i.e. a failure of several redundant system trains must be prevented. This applies in particular to external hazards which, like the earthquake, lead to a simultaneous loading of all trains of the residual-heat removal system.

3 Background

Section 3.1 deals with the design of the closed cooling water and service water systems on the basis of the discussions among the RSK Committee on PRESSURE-RETAINING COMPONENTS AND MATERIALS (DRUCKFÜHRENDE KOMPONENTEN UND WERKSTOFFE – DKW). Section 3.2 deals separately with buried piping systems. Subsequently, the measures for operational monitoring and the in-service inspections are described in summary. In addition, the existing regulatory requirements are compiled. Further details of the technical design of the systems are presented in Chapter 5 'Assessment'.

3.1 Design of the closed cooling water and service water systems

The requirements for the design of the closed cooling water and service water systems were specified according to their classification.

Within the framework of the licensing procedures for the German nuclear power plants, a safety classification of plant components was carried out. Part of this safety classification is the division of components and systems into so-called classes or classification grades. These reflect the safety-related requirements for the stability, integrity and function of components. The requirements belonging to the respective classes or classification grades have been defined in specifications. They are part of the licence and contain the requirements – graded according to their safety-related significance – for the choice of materials, manufacture, design, stability, and the test steps required for quality assurance.

For BWR plants of construction line 72, whose specifications were prepared before the introduction of the Generic Specification on Basic Safety and the relevant Safety Standards of the Nuclear Safety Standards Commission (KTA), the systems and components were classified in classification grades AS 1 to AS 5; these are largely comparable to the classification of the Konvoi plants in classes K 1 to K 5 (see below). The design and quality requirements assigned to the classification grades were specified on the basis of the German regulations for pressure vessels and steam boilers, supplemented by additional nuclear requirements. Requirements from the US regulations (ASME Code) were included.

For these plants, the RE-L 1508 specification for piping of the water/steam cycle, the reactor auxiliary systems (TH and TF, among others), the supporting systems and the cooling water systems (VE, among others) were applicable at the time of construction [3]. This specification contains criteria for all classification grades and criteria for the assignment of the systems to the different classification grades.

For the BWR plants of construction line 72, the plant components were thus classified according to the criteria of specifications RE-L 1508 to RE-L 1708. According to these specifications, the following criteria apply for the assignment to the different classification grades [3]:

- AS 1: Components of the reactor coolant pressure boundary
- AS 2: Components connected to the reactor coolant system and having safety significance for reactor shutdown and residual-heat removal as well as all connecting lines up to and including the first isolation.
- AS 3: Components having safety significance or retaining activity as well as all connecting lines up to and including the first isolation.
- AS 4: Components that neither have safety significance nor retain activity and whose pressure area product is > $5 \cdot 10^3$ bar cm^2.
- AS 5: Components that do not fall under classification grades 1 to 4.

In the BWR plants of construction line 72, the nuclear residual-heat removal systems TH were classified in AS 1 and AS 2, depending on the system sector [4]. The nuclear closed cooling water systems TF were classified in AS 3. The nuclear service water systems VE were also classified in AS 3, with the exception of the outlet into the river (concrete pipes DN 1200), which was classified in AS 5. [5], [6]

Note: The additional independent residual-heat removal system (ZUNA), which was retrofitted in later years (from 1993) on the basis of KS D specifications for Konvoi, will not be discussed here.

The PWR nuclear power plants of the pre-Konvoi series were constructed after the publication of the Generic Specification on Basic Safety for PWRs [7]. In these plants, the nuclear closed cooling water system and the service water system are designed as basically safe systems and thus meet the requirements of the Generic Specification on Basic Safety.

The components and systems of the Konvoi plants were divided into classes K1 to K5. For the pressure-retaining components of Class K1, the specified requirements correspond to the requirements of KTA 3201.1, 3201.2 and 3201.3. The requirements for pressure-retaining components of Class K2 correspond to those of KTA 3211.1, 3211.2 and 3211.3.

For classes K3 to K5, further graded requirements have been defined which are based on the codes and standards for conventional plants (e.g. AD regulations of the German Working Group on Pressure Vessels, DIN, Technical Standards for Steam Boilers) and provide for supplementary verifications e.g. for class K3. For Class K3/K4a piping, for example, these requirements have been laid down in Specification KS D 3041/50 [3].

The procedure for fulfilling the verification objectives was summarised in component specifications for the Konvoi plants. For component classes K2 and K3, the following specifications were applicable to the Konvoi plants at the time of construction:

- KS D 2021/50 and 3021/50 for valves,
- KS D 2031/50 and 3031/50 for pumps, and
- KS D 2041/50 and 3041/50 for piping.

In the licensing procedure, the nuclear residual-heat removal systems JN were classified as Class K2 in the classification of the components on the basis of the safety-related significance of the systems of the Konvoi plants. An exception to this rule are the feed lines from the flooding tanks to the first isolating valve, which, like the closed cooling water and service water systems (KAA, PE/PJ), are subjected to low pressure and low temperature. These low-energy systems and the above-mentioned feed lines of the nuclear residual-heat removal systems are classified as Class K3. With the gradation from K2 to K3 [8], the plant vendor KWU suggested deviating from the requirements of the Generic Specification on Basic Safety for these systems.

In a letter by KWU of 1983 on the classification of systems in the Konvoi plants [8], the following is stated:

> *"The difficulties associated with the implementation of the requirements contained in the "Generic Specification on Basic Safety" in the current licensing procedures have meanwhile become apparent to the RSK, and the conventional codes and standards have increasingly been considered and appreciated as a reference basis for the work on the KTA Safety Standards. Recognising that improvements of the KTA Safety Standard compared to the previous state of discussion formally violate the requirements of the RSK Guideline, KWU reported to the RSK in letters of 8 October 1981 and 18 March 1982 on the amendments that become necessary from our point of view. These amendments aimed in particular at adaptations of the requirements for special quality characteristics and quality verifications for low-pressure and low-temperature systems (closed cooling water system, service water system, suction lines of safety systems) that are acceptable from an engineering point of view. At a meeting on 31 March 1982, the RSK Subcommittee on Light Water Reactors showed understanding for our concern but did not agree to make selective amendments in the intended sense and wanted to wait for the presentation of a cohesive KTA Safety Standard including detailed specifications for quality assurance measures. In the minutes of the 175th RSK meeting on 31 April 1982, it says the following, amongst other things, about the results of the 51st meeting of the RSK Committee on LWRs on 31 March 1982:*

'The "Committee on Light Water Reactors" does not at present see the need for an immediate amendment of the annexes to the Guidelines, as the deficiencies criticised can be avoided by expert interpretation. With regard to the further procedure, the Committee proposed that first of all, the work in the corresponding KTA subcommittee should be completed. The developed proposals should then be discussed within the "Committee on Pressure-Retaining Components." The RSK can then decide whether an amendment (e.g. a specification) of the annexes to the Guidelines is useful or whether the list of systems should be modified.'"

The above classification of the systems became the basis for the licensing of the Konvoi plants.

The differences resulting for the components are described in Chapter 5.

3.2 Buried piping

In the buried area of the service water systems, special materials and designs such as ductile cast iron or concrete pipes were used in various plants due to the special stresses and strains (e.g. corrosion). The conditions for this had to be specified in each individual case in agreement with the authority and the authorised expert consulted by the authority (cf. Generic Specification on Basic Safety, Section 3.3). This was done within the framework of the construction of the plants in each case by specifying and applying reviewed and officially approved specifications or additional quality specifications (*zusätzliche Gütevorschriften* – ZGV) for these applications, on the basis of which all requirements regarding design, construction, calculation, materials and manufacture were specified in analogy to the other metallic materials.

An example of the procedure is given for a Konvoi plant. There, the underground pipelines, which were made of prestressed concrete, were designed, manufactured and laid using an additional quality specification (ZGV).

This quality specification specifies i.a. the following:

- construction/design as prestressed-concrete pressure pipes,
- determination of the specifications to be used for the design,
- design, manufacture, quality assurance and execution according to the components catalogue,
- pipe laying according to phase plans,
- specifications for trench reinstatement,
- increased frequency of construction supervision,
- train-by-train pressure test before commissioning, and
- computational verifications for external hazards (safe shutdown earthquake) and malicious acts (blast wave).

In addition, the condition as specified is monitored by regular operational monitoring, e.g. by visual and internal inspection of the piping.

3.3 Operational monitoring, in-service inspections (ISI) and surveillance testing

The RSK's DKW Committee asked a working group composed of experts from the Committee to compile, with support of external experts, the measures of operational monitoring, in-service inspections and surveillance testing that are typically implemented in German nuclear power plants. These measures are summarised in the following. No significant differences between pre-Konvoi and Konvoi plants and BWR plants were identified during the compilation.

3.3.1 Operational monitoring

Operational monitoring includes the assessment of the operating behaviour of the systems based on operating parameters such as pressure, temperature and mass flows.

Plant inspections are a further building block of operational monitoring. The plant inspections serve to check the proper (external) condition of the systems. Here, the checks are carried out with regard to the operating behaviour of the individual components (e.g. vibration behaviour, running and flow noise) and the tightness of the system.

3.3.2 In-service inspections (ISI) and surveillance testing

The scope, type and intervals of testing are determined according to the safety significance of the systems and components. They are implemented in testing schedules in which the corresponding test instructions are established. In addition to the specifications from the codes and standards, operating experience is also taken into consideration in the testing schedules.

System walkdowns

The system walkdowns as part of the ISI programme serve to thoroughly examine the external condition of the system and are usually carried out once a year with participation of the authorised expert.

Non-destructive tests

Non-destructive tests comprise visual inspections of

- vessel surfaces,
- components (valves and pumps) and
- piping in the area of dismounted components.

Visual inspections of the surfaces of vessels and their components are carried out in a cycle of four years (in some areas of five years). The scope of testing includes the examination of an existing coating for any damage.

During an inspection of components, the component parts as well as the housings are subjected to a visual inspection. The inspection intervals vary between four and twelve years, depending on operating experience. The determination of the cycles is based on the knowledge of the existing damage mechanisms and from the operation of the systems of the licensee’s own plant as well as the feedback of generic operating experience.

A visual inspection of the connected piping is carried out as part of the inspection of the components.

Non-destructive in-service inspections on representative welds are performed as surface, visual, ultrasonic and/or radiographic examinations. The extent of the tests is determined plant-specifically.

Further non-destructive tests, like e.g. eddy-current tests of heat exchanger tubes, are determined plant-specifically depending on operating experience. In addition, further inspections are carried out as part of planned maintenance measures.

Pressure testing

Pressure tests are carried out according to the specification for pressure vessel tests in the conventional regulations in a cycle of eight years (in exceptions, ten years).

In addition to the inspection of the vessels, plant-specific system pressure tests are carried out. Within the scope of these pressure tests, the integrity of the pipe sections is tested in addition to the system and plant walkdowns.

3.4 Regulatory requirements

This section first describes how the closed cooling water and service water systems are to be classified according to the RSK Guidelines for Pressurised Water Rectors [9] and the Safety Requirements for Nuclear Power Plants (SiAnf) [10]. Then, an overview of the KTA Safety Standards applicable to these systems with regard to their design is given. Finally, the regulatory requirements regarding operational monitoring, in-service inspections (ISI) and surveillance testing are dealt with.

According to the RSK Guidelines [9], the systems of plants with PWRs have to be assigned to Group I of the "external systems" if one of the three criteria in Section 4.2.1 is fulfilled. The three criteria are:

1 The component is necessary for the control of design basis accidents with regard to shutdown, maintenance of long-term subcriticality, and residual-heat removal.

2 In case of failure of the component, large amounts of energy will be released, and the consequences of the failure will not be limited to an acceptable level with regard to nuclear safety by structural measures, physical separation, or other safety measures.

3 The failure of the component may lead directly or in a chain of postulated consequential events to a design basis accident (according to the BMI Guidelines for the Design of Nuclear Power Plants against Design Basis Accidents) as defined in Section 28 para. 3 StrlSchV (former version of the Radiation Protection Ordinance).

If at least one criterion is fulfilled, the "Generic Specification on Basic Safety of Pressure-Retaining Components" [7] has to be applied for the pressure-retaining components of these systems. The Generic Specification contains requirements which, if met, result in a basic safety of the components of the "external systems" which precludes a catastrophic failure of a component due to manufacturing faults.

In addition, the Generic Specification on Basic Safety [7] contains in Sections 6.3 and 6.4 requirements for ISI on piping, valves and pumps. According to these requirements, in-service inspections have to be carried out mainly on representative pipe welds and locations subject to special loading. Examples are given for such locations. The tests and inspections have to be performed such that within a period of eight years the representative extent of testing agreed upon with the authority or the authorised expert commissioned by the authority (Sec. 20 Atomic Energy Act) is covered. The reactor plant vendor and the licensee have to prepare plans for the performance of in-service inspections and agree them with the authority or the authorised expert commissioned by the authority. Requirements for operational monitoring are not specified in the Generic Specification.

The nuclear closed cooling water system and the service water system are low-energy systems which belong to the external systems according to Criterion 1. Accordingly, Annex 1 of the RSK Guidelines for PWRs [9], which lists the systems to be assigned to Group I of the external systems, also lists the systems JN, KAA and PE/PJ belonging to the emergency core cooling and residual-heat removal chain. They are assigned to Test Group A3 in accordance with the Generic Specification on Basic Safety [7].

In the further development of the regulatory requirements, a change has occurred in this respect. In the Safety Requirements for Nuclear Power Plants, Appendix 1 [10], Criterion 1 reads as follows:

> *"The component is necessary for the control of events on levels of defence 3 and 4a with regard to shutdown, maintenance of long-term subcriticality and direct residual-heat removal".*

Thus, the definition of the external systems, like in the Safety Standards of the KTA 3211 series (as described below), was restricted to the systems of direct residual-heat removal, i.e. the nuclear residual-heat removal systems JN and TH, respectively. Hence the requirements formulated in Section 3.4 of the SiAnf regarding the basic safety of the external systems do not apply to the nuclear closed cooling water and service water systems.

In the KTA Safety Standards, the requirements for the fulfilment of the acceptance criteria for the residual-heat removal systems are specified in the Safety Standards mentioned below:

- general requirements for the residual-heat removal systems in KTA 3301,
- general requirements regarding seismic events in ´KTA 2201.4,
- requirements for the design, calculation, construction, materials and manufacture in the KTA Safety Standards 3211.1-3.

In KTA 3301 "Residual Heat Removal Systems for Light Water Reactors" [11], the requirements for

- the functional design,
- the structure and the functional safety,
- the layout,
- the operation, and
- the monitoring and inspection

of the residual-heat removal systems are laid down.

This also includes the systems

- nuclear closed cooling system for safety-relevant equipment (KAA or TF, depending on plant generation),
- secured part of the service water system (PE or VE), and
- closed cooling system for non-nuclear safety-relevant equipment (PJ or VJ).

In addition to the requirements for specified normal operation and plant-internal design basis accidents, Section 3 "Specified Demand Cases" of KTA 3301 also defines requirements for external hazards, e.g. earthquakes.

The requirements for the design of the mechanical components of the emergency core cooling and residual-heat removal systems result from the design boundary conditions comprising the failure assumptions, the redundancy requirements, and the layout and structural design.

Failure assumptions and redundancy requirements are applied to stipulate e.g. that the consequences of design basis accidents and consequential failures have to be limited in such a way that it remains ensured that design basis accidents in case of a single failure and unavailability due to maintenance measures are controlled.

The acceptance criteria for operation, for plant-internal design basis accidents and for external hazards, e.g. earthquakes, depend on the requirements for the respective mechanical components and systems.

Regarding the requirements, a differentiation is made between

- load-carrying capacity (support stability),
- integrity and
- operability.

The load-carrying capacity is the ability of components to withstand the postulated impacts through strength, stability and positional safety (e.g. safety against falling over, crashing, inadmissible slippage). The load-carrying capacity (support stability) has to be demonstrated for the component and its support. The loads resulting from the interaction with building structures must be specified.

Integrity is the ability of a component to meet the requirements for strength, resistance to fracture and tightness beyond its load-carrying capacity. The requirements for the proof of integrity can be found in the component-specific codes and standards.

Functionality is the ability of a system or component, over and above its load-carrying capacity and integrity, to perform the intended tasks by means of appropriate mechanical or electrical function.

With regard to the requirements regarding earthquakes, KTA Safety Standard 2201.4 "Design of Nuclear Power Plants against Seismic Events, Part 4: Components" [12] is applicable. In accordance with para. 3.1 of KTA 2201.4, a distinction has to be made as to whether the functional capability must be ensured

- after the earthquake or
- during the earthquake and after the earthquake.

A further distinction has to be made between active and passive functionality.

Active functionality of the component ensures that the specified movements (relative movements between parts) can be performed (no closing of play, no creation or change of friction forces) and that the electrical functions are guaranteed.

Passive functionality of the component means that permissible deformations and displacements are not exceeded.

The KTA 3211 series is considered to be the implementation of the "Generic Specification on Basic Safety of Pressurised Components" for external systems at the level of the safety standards. In KTA Safety Standards 3211.1, 3211.2 and 3211.3, the result of the coordination phase for the Konvoi plants was taken into account by the following formulation regarding the scope of the KTA 3211 series:

> *"The plant component is needed to cope with incidents regarding shutdown, maintenance of long-term subcriticality and direct residual heat removal.*
> *Requirements to be met by components in systems which only indirectly serve residual heat removal, i.e. the nonactivity-retaining closed cooling water systems and service cooling water systems, shall be specified in a plant-specific manner, taking into consideration multiple design (e.g. redundancy, diversity)."*

Thus, the closed cooling water and service water systems – in accordance with the classification in the Safety Requirements – are not included in the scope of KTA Safety Standards 3211.1-3.

Regarding operational monitoring and in-service inspections/surveillance testing, KTA Safety Standard 3301 "Residual Heat Removal Systems of Light Water Reactors" has to be mentioned first. In this KTA Safety Standard, measures for the monitoring of system variables are specified on the one hand in the section "Operation and Monitoring". On the other hand, the section on "In-service inspections" primarily specifies requirements for functional tests. Regarding non-destructive tests, reference is made to KTA 3211.4 which – as the title clearly indicates – specifies the requirements for in-service inspections and operational monitoring of the external systems [13].

KTA 3211.4 specifies the requirements for in-service inspections/surveillance testing of pressure and activity-retaining components outside the primary system. Accordance to the defined scope of KTA 3211.4, the closed cooling water and service water systems are not covered by this standard.

On the other hand, KTA 3211.4 specifies the following in Section 5.2.1.1 (7):

> *"Sea and river water-wetted components and systems shall be examined for corrosion damage. The test intervals shall be determined individually for each plant in due consideration of*
>
> *a) possible concentrations of damaging substances (stagnating fluid during operation, dead spaces)*
>
> *b) possible damage to internal linings (e.g. increased flow rate, turbulence, repair zones)."*

This describes requirements that apply exclusively to the service water system, which is excluded from the scope. For other systems that are excluded from the scope, such as closed cooling water systems, no requirements are specified.

Furthermore, the regulations on ageing management have to be observed. Irrespective of the classification into component classes or classification grades, the components of the emergency core cooling and residual-heat removal systems, being components of a safety-relevant system, at least have to be assigned to the Group "M2 components" in accordance with KTA 1403 "Ageing Management in Nuclear Power Plants" [14]. KTA 1403 specifies that the procedure for maintaining the required quality of the Group M2 components is based on preventive maintenance. This means that the consequences of service-induced damage mechanisms are monitored at representative locations, the findings from the operation of other plants are taken into account, the state of knowledge regarding possible damage mechanisms is monitored and evaluated in accordance with the state of the art in science and technology, and systematic failures due to ageing-related defects are prevented.

4 Assessment criteria

The questions posed by the BMUB include the following aspects:

- operational monitoring,
- load spectrum to be considered,

- with reference to the latter, the question of safety margins, and
- the higher-level requirements specified in the RSK Guidelines and Safety Requirements as well as
- suitability of the requirements made in the codes and standards.

In the following, these aspects are put in concrete terms by means of assessment criteria, starting from the higher-level safety requirements.

In the RSK Guidelines for Pressurised Water Reactors [9] and the corresponding Generic Specification on Basic Safety [7], requirements are laid down which, if fulfilled, allow the exclusion of a catastrophic failure due to manufacturing faults. This is the higher-level requirement with regard to the pressure-retaining components of the external systems which, according to the RSK Guidelines with their annexes, also include the closed cooling water and service water systems of pressurised water reactors.

According to the Safety Requirements for Nuclear Power Plants (SiAnf) [10], these systems are not included in the external systems, as shown above. Higher-level safety requirements with regard to the design and quality of the components of safety systems are formulated in Section 2.1 (13) of the SiAnf:

> *2.1 (13) The measures and equipment of levels of defence 1 to 4a as well as the measures and equipment needed for internal and external hazards as well as for human-induced external hazards shall meet stringent requirements with regard to the quality and reliability of planning, implementation and execution of the measures and the design, manufacturing, construction and operation of the equipment. The requirements for quality and reliability are guided by the safety significance of the measures and equipment.*

Regarding the load cases to be considered, the higher-level requirements are defined in Section 2.1 (5) of the SiAnf:

> *2.1 (5) The safety system as well as the emergency equipment shall be designed such that they will remain effective in the event of internal and external hazards.*
>
> *Impacts resulting from very rare human-induced external hazards must not lead to safety equipment failures in such a way that the necessary safety functions are no longer effective; otherwise, specially designed equipment shall be provided for this case so that event sequences of level of defence 4b are prevented.*

Thus, the impacts from inside and outside that must be taken as a basis for the design according to the SiAnf have to be regarded as the load spectrum. The closed cooling water and service water systems that are not directly connected to the reactor coolant pressure boundary and are not located in the containment are not affected by any dynamic loads from loss-of-coolant accidents. Moreover, the different trains of the systems are physically separated. Therefore, the crucial design basis loads affecting several redundant trains are the earthquake loads. As beyond design basis loads, the loads resulting from the man-made hazard conditions aircraft crash and blast wave have to be considered.

Sufficient safety margins in the sense of the BMUB's question are given if the requirements of the SiAnf in 3.1 (2) a) "well-founded safety factors in the design of components depending on their safety significance; here, established rules and standards may be applied with regard to the case of application;" are fulfilled. This is met, for example, if margins as in the case of a design in accordance with the Generic Specification on Basic Safety exist. For man-made hazard conditions, the requirements applicable in accordance with the current higher-level regulations (SiAnf, BMI Guideline on Blast Wave) are used.

As regards operational monitoring and in-service inspections/surveillance testing, the measures envisaged here are mirrored on operating experience in order to check whether ageing mechanisms or other damage that could lead to the failure of several trains of the physically separated systems are detected in good time.

The question of the establishment of the requirements in the codes and standards is answered on the basis of the results of the technical evaluation and by checking completeness of the Safety Standards of the Nuclear Safety Standards Commission (KTA).

The design and manufacture of buried pipes will not be evaluated in this Statement as the conditions for buried pipes vary from plant to plant.

The seismic robustness is assessed according to the criteria of the RSK-SÜ. The robustness in case of an aircraft crash is not dealt with here since there have been separate RSK discussions in this respect, which have meanwhile been concluded for the Konvoi plants.

5 Assessment

5.1 Safety margins

The safety margins against failure of safety-relevant components during operation or during the design basis accidents to be considered as well as external hazards and man-made hazard conditions depend on a number of factors in design and construction:

1. the material used and its processing,
2. the dimensioning (here: wall thickness),
3. the permitted stresses in relation to the given tensile strength or yield strength of the material (design stress intensities),
4. the assignment of the relevant load cases to loading levels with their corresponding requirements,
5. the conservativeness of the load assumptions (e.g. conservativeness of the earthquake ground acceleration spectrum used),
6. the respective design,
7. the support concept,
8. further conservative assumptions in the calculation procedure for the verifications.

Factors for which there are relevant differences between pre-Konvoi and Konvoi plants and BWRs of construction line 72 are discussed below. This is followed by a summarising assessment with regard to the safety margins given by the totality of the factors.

5.1.1 Materials and manufacture

According to the Generic Specification on Basic Safety [7], ferritic materials of the material group WII (WStE 26, 29, 32, 36, C22.8, 15Mo3, St35.8, St37-3, GS-C25) and austenitic materials (1.4550, 1.4580, 1.4541, 1.4571, 1.4552, 1.4581) may be used for pipes, pumps and valves as well as pressure vessels under low-energy operating conditions. Compared to the materials according to conventional codes and standards, various alloying elements (such as P, S, Cu, V) are further restricted for the materials according to the Generic Specification on Basic Safety in order to increase toughness, workability and resistance to intergranular corrosion (in the case of austenite).

Fracture toughness requirements were defined for the ferritic materials, requiring an impact energy of 41 Joule (ISO-V notched bar impact test, transverse, mean value) at the lowest loading temperature for the base material (*Grundwerkstoff* – GW), the weld metal (*Schweißgut* – SG) and the heat-affected zone (*Wärmeeinflusszone* – WEZ). For austenitic materials, impact energies of at least 70 Joule in unannealed condition and 55 Joule in annealed condition have to be demonstrated.

In the Generic Specification on Basic Safety, the scope of non-destructive testing on the semi-finished products is defined depending on the product form (sheets, forgings, pipes, cast steel).

In the Konvoi plants and in the BWR plants of construction line 72, ferritic materials[1] were used in the closed cooling water and service water system according to class K3 and AS 3, e.g. material St 37-2 (impact energy requirements according to AD Rules 27 J (mean value), 19 J (smallest single value) at 20 °C). In the pre-Konvoi plants, the specified materials of material group WII were used in accordance with the Generic Specification on Basic Safety, e.g. material St 37-3 (impact energy 41 J (mean value), 29 J (smallest single value) at lowest loading temperature (0 °C or 20 °C)) for the main piping of the service water system in accordance with [15]. For the Konvoi plants, the specifications for Class K3 contained analysis restrictions – similar to the Generic Specification on Basic Safety – for the phosphorus and sulphur contents, but not for the BWR plants of construction line 72. With regard to the requirements for material acceptance and submittal of certificates, there are no significant differences between K3 and the Generic Specification on Basic Safety, material group WII in combination with test group A3.

The requirements set out in K3 and AS 3 imply that at least all requirements as set out for conventional pressure equipment (Pressure Vessel Ordinance, AD technical rules) must be fulfilled. The requirements regarding notched-bar impact strength in accordance with conventional requirements for the prevention of brittle fracture (e.g. for the material St 37-2, impact energy 27 joules at room temperature sufficient for operating temperatures of the medium down to -10 °C, [15]) have been reduced compared to the requirements of the Generic Specification on Basic Safety.

[1] Austenitic materials are not used in the main trains of these systems, so they are not considered here.

Only manufacturers qualified on the basis of AD technical rule W0 whose manufacturing facilities, manufacturing and testing personnel and quality assurance systems had been checked accordingly were permitted to manufacture the materials/product forms according to K3 and AS 3. The respective requirements of the Generic Specification on Basic Safety are complied with.

For the manufacture and the support structures of the components in the plant, requirements are made for the manufacturer's qualification, the qualification of the welding techniques and quality certificates of the welded joints, for the production/review documents as well as for production monitoring, final inspection and documentation in accordance with the Generic Specification on Basic Safety. For the welded joints, it had to be demonstrated by means of welding technique qualifications and production weld tests that the requirements placed on the base materials (impact energy 41 joules for W II materials) were also fulfilled for the weld metal and the heat-affected zone. The manufacturer had to subject the seam welds to a 100 % surface examination and at least 10 % to a volume examination (radiography or ultrasonic) in accordance with the Generic Specification on Basic Safety [7] Test Group A3.

The comparison with the requirements according to the K3 specifications for the Konvoi plants shows that there are no significant differences to the Generic Specification on Basic Safety (Test Group A3) with regard to the qualification requirements for the manufacturing companies and their welding and testing personnel as well as regarding the required manufacturing/review documents and their review by the manufacturer, plant vendor, and authorised expert [3]. This also applies to the requirements for BWR plants in accordance with the RE-L specifications 1508 [3] in classification grade AS 3.

Likewise, there are no significant differences regarding the proof of suitability of the filler materials and the quality certificates of the welded joints. Production monitoring and documentation is also regulated similarly and is carried out with participation of the authorised expert as an independent inspection party.

Differences result – as in the case of the base materials – in the proof of toughness of the welded joints, i.e. weld metal and heat-affected zone (requirement according to AD-HP 2/1 = 27 Joule at lowest operating temperature) and in the required scope of the non-destructive tests on the welded joints which, in deviation from the requirements of the Generic Specification on Basic Safety (scope of tests see above) in K3, is only required with a random surface examination and a scope of the volume test with H = 10 % for longitudinal welds and H = 5 % for circumferential welds. In the case of circumferential welds in BWR plants, AS 3 required of the manufacturer a test scope of 10 % for the surface and volume inspection.

To protect the pipes of the service water systems and their components against corrosion, coatings (e.g. cement mortar linings, tar epoxy resin coatings, rubber coatings) and paints were applied to the interior and, in the buried area, to the exterior surfaces. These were produced according to qualified methods and applied in accordance with valid manufacturing specifications.

With regard to the materials used and the requirements for manufacturing quality, it can thus be summarised that in the comparison of what is specified according to the K3-specifications for the Konvoi plants and according to RE-L 1508 for AS 3 (BWR construction line 72), there are differences in the impact energy and in the scope of testing for the verification of manufacturing quality compared to the Generic Specification on Basic Safety. In the case of the BWR construction line 72, there are also differences in the permissible phosphor and sulphur contents.

Regarding a sufficiently tough material behaviour to avoid brittle fracture due to internal pressure loading, the RSK considers that sufficient safety margins exist for these systems due to compliance with the specifications of the conventional codes and standards (impact energy at 20 °C at least 27 J). This assessment is based on the following consideration: The impact energy as a measure of toughness is an important parameter with regard to the prevention of brittle fracture failure and to limiting crack propagation. For the systems under consideration, this also covers the influence of sulphur and phosphor. In the systems under consideration here, the stress level in the pipes is very low in normal specified operation (below 50 N/mm², see Section 5.1.2). There are large safety margins in comparison to the permissible stress (yield strength at least 235 N/mm²). Pressure transients which lead to a significant increase in stress in comparison to this need not be postulated for these low-energy systems according to the design. Therefore, a spontaneous failure or significant crack growth due to internal pressure need not be considered. Furthermore, the systems do not experience any significant temperature transients that would lead to additional stresses due to thermal expansion.

5.1.2 Dimensioning and analysis of the mechanical behaviour

a) Dimensioning

Within the scope of dimensioning, the load-carrying cross-sections (wall thicknesses) have to be specified such that the stresses resulting from internal pressure, external pressure and additional loads (e.g. positioning forces) do not exceed the specified primary stress limits of loading level 0 and, if relevant, of loading levels A to D [16].

Dimensioning is based on the loads specified in design specification sheets (*Auslegungsdatenblätter* – ADB) for components or in pipe load specifications (*Rohrleitungsbelastungsangaben* – RBA) for pipes, applying design formulas.

For Konvoi plants, the calculated verifications of components and pipes of the systems KAA, PE and PJ in component class K3 were carried out in accordance with Section 5 of the component specifications KS D 3021/50E, KS D 3031/50D, KS D 3041/50D. The permissible stresses were determined on the basis of the stress comparison value S_m according to Section 5.2 of the above specifications. For the components and systems affected here with a design temperature < 80 °C, $S_m = R_{mRT}/3$ is applied in the case of ferritic steels and in the case of ferritic cast steel[2] $S_m = R_{mRT}/4$ with R_{mRT} as minimum requirement for tensile strength at room temperature.

[2] Note: To simplify the presentation, only the determination of the comparative stress value with the tensile strength at room temperature R_{mRT} is described, since this value is relevant for the ferritic systems with design temperatures < 80 °C to be considered here.

According to RE-L 1508, for BWR construction line 72 the stress comparison value for ferritic steels for AS 3 is specified as $S = R_{mT}/3$ (with R_{mT} as minimum requirement for the tensile strength at design temperature) [3]. For the design temperature of 100 °C applicable to BWRs, the allowable stress is thus slightly lower than according to component class K3.

The components and piping of the comparable external systems of the pre-Konvoi plants, which have been fully demonstrated to fulfil the requirements specified in the Generic Specification on Basic Safety applying to pressure-retaining components, are classified in material group WII, test group A3. For these systems, the design stress intensity for both ferritic steels and cast steels is determined as $S = R_{mRT}/4$ in accordance with the currently valid KTA 3211.2, Table 6.6-1 [16].

At the design pressures of 6 bar to 14 bar prevailing here, however, the dimensioning of the wall thickness is not determined by the stress criterion derived from the design calculation. Rather, the wall thicknesses resulting from production and design conditions fulfil the wall thickness requirement from the design calculation. For example, the 50 N/mm^2 criterion, i.e. a nominal operating stress $P_{mNB} < 50\ N/mm^2$, is met for all pipe dimensions in Konvoi plants.

A comparison of the pipe dimensions of the pre-Konvoi plants, which were designed in accordance with the Generic Specification on Basic Safety, with those of the Konvoi plants to which the conditions of the K3 specifications apply, shows that the wall thicknesses of the Konvoi plants are at least equal to those of the pre-Konvoi plants, and in the case of the closed cooling water system are significantly greater than those of the pre-Konvoi plants, especially for the larger diameters. This is shown in Table 5-1 using the example of the closed cooling water systems. It should be noted that although the design pressure of the closed cooling water system in the Konvoi plants is higher than in the pre-Konvoi plants, the operating pressure is not. In the service water systems, the design pressures and temperatures as well as the diameter-to-wall-thickness ratio of the large pipes are identical in both pre-Konvoi and Konvoi plants [15].

For the BWR construction line 72, an exemplary comparison of the diameter-to-wall-thickness ratio in the closed cooling water and service water systems has shown that for pipes up to a nominal diameter of 100 mm (NB100), the wall thicknesses are same as for PWRs, but that for larger diameters, pipes have lower wall thicknesses than those in the Konvoi/pre-Konvoi plants.

Table 5-1: Pipe dimensions for the nuclear closed cooling water system TF and KAA, respectively, for exemplary pre-Konvoi/Konvoi plants and BWR construction line 72 ([17] and plant-specific information).

Pre-Konvoi plant, system TF/KAA (ferrite) Design P_0 = 10 bar				**Konvoi plant, system KAA (ferrite) Design P_0 = 14 bar**				**BWR construction line 72, system TF (ferrite) design P_0 = 8.5 bar**			
NB	Diameter D [mm]	Wall thickness t [mm]	D/t	NB	Diameter D [mm]	Wall thickness t [mm]	D/t	NB	Diameter D [mm]	Wall thickness t [mm]	D/t
700	711	10.0	71.1								
				600	610	10.0	61.0	600	609.6	6.3	96.8
500	508	8.0	63.5	500	508	11.0	46.2	500	508	6.3	80.6
450	457	8.0	57.1	450	457	10.0	45.7				
				400	406.4	8.8	46.2				
300	323.9	8.0	40.5								
				125	139.7	4.0	34.9				
100	114.3	4.0	28.6	100	114.3	4.0	28.6	100	114.3	4.0	28.6
80	88.9	3.2	27.8	80	88.9	4.0	22.2	80	88.9	4.0	22.2
50	60.3	4.0	15.1	50	60.3	4.0	15.1	50	60.3	4.0	15.1
				50	60.3	3.2	18.8				

b) Analysis of the mechanical behaviour

The calculatory verification of integrity, stability and functionality is provided by the analysis of the mechanical behaviour (*Analyse des mechanischen Verhaltens* – AdmV) in accordance with the requirements for the component or system.

For the components and pipes of the KAA, PE and PJ systems of the Konvoi plants, these verifications were carried out, as described during dimensioning, in accordance with Section 5 of the above-mentioned component specifications KS D 3021/50E, KS D 3031/50D, KS D 3041/50D. The verifications of the component support structures and pipelines with non-integral supports were performed in accordance with KS D 4573.1 for the Konvoi plants.

According to RE-L 1508, the pipe calculations for BWRs for both AS 2 and AS 3 have to be performed with the same formulae as for pipes of Test Groups A2 and A3 in accordance with KTA 3211.2 (see [16], Section 8.5.3), albeit with different stress coefficients B_i that lead to slightly lower equivalent stresses. The loads to be covered and calculations to be performed in AS 3 differ from AS 1 only in that operational vibrations, temperature transients and design basis accident loads need not be considered (except for the earthquake load case for the systems considered here). With regard to the permissible loading, the operating base earthquake was treated as specified normal operation and the safe shutdown earthquake (corresponds to the design basis earthquake in today's sense) was treated as a design basis accident (emergency in the sense of the classification of KTA 3211.2, i.e. loading level C). Altogether, the analyses for BWR construction line 72 were performed in accordance with the classification of KTA 3211.2.

The analyses of the mechanical behaviour were generally carried out for the earthquake load case according to response spectra methods when performing a linear-elastic calculation. The stress analysis of pipe components was carried out using the stress index method. The stress determined on the undisturbed pipe from internal pressure and moment loads is multiplied by the stress increase factors for bends, T-sections, reductions or other discontinuities as specified in the relevant codes and standards (ASME, KTA) for the respective components.

In Table 5-2 below, the detailed boundary conditions for the verifications of piping systems in the earthquake load case of the pre-Konvoi and Konvoi plants as well as the BWR construction line 72 are compared. The table shows that in the case of the boundary conditions for the verification of piping systems, there are no relevant differences between the pre-Konvoi and Konvoi plants nor the BWR construction line 72 regarding

- calculation scope (pipes NB > 50),
- calculation rules and codes and standards (ASME NC 3650 ff),
- modelling principles and
- system damping (D = 2 % for NB < 300, D = 3 % for NB ≥ 300)

Table 5-2: Comparison of boundary conditions for the analysis of the mechanical behaviour (AdmV) of piping systems [20]

	Analysis of the mechanical behaviour, closed cooling water and service water systems			
	Pre-Konvoi "basically safe"[3]	**Konvoi K3 systems[4]**	**AdmV "K3 systems today"**	**BWR construction line 72**
Calculation scope	NB > 50	NB > 50 with internal/external hazard	NB > 50 with internal/external hazard	NB > 50 with internal/external hazard
Calculation rules, codes and standards	RE-L 3396 (for KBR), Section. 4.4 corresponds to NC 3650	ASME Sect.III, Subsect. NC 3650 Edition 80, Add. 82 (ggf. NB 3200)	KTA 3211.2	Piping in RE-L 1508, Section 4 Pipe supports in RE-L 2408, Section 4
Design stress intensity	S acc. To Section 4.4.2.1 of RE-L 3396 → $R_{mRT}/4$	S acc. to KS D 3041/50 → $R_{mRT}/3$	S_m acc. to KS D 3041/50 → $R_{mRT}/3$	Permissible stresses for design (RE-L 1508, Ch. 4.2.2.3.1, equation 1) Min ($R_{p0,2T}/1.5$ or $R_{mRT}/3$)
Loading levels safe shutdown earthquake (design basis earthquake) load case	Level D Response spectra «site-specific»	Level D Response spectra «enveloping» Konvoi and in some areas «site-specific»	Level D Response spectra «site-specific»	Operating basis earthquake as normal specified operation, safe shutdown earthquake as design basis accident (emergency) Site-specific floor response spectra
Load classification (load case combination)	K2/A2/A3	as K2/A2/A3	as K2/A2/A3	analogous to K2/A2/A3

3 RE-L 3398 Specification for piping within the scope of the Generic Specification on Basic Safety, RSK Guidelines Chapter 4.2 "External Systems" Brokdorf Nuclear Power Plant (KBR)
4 Techn. Report V29/83/125a – KWU Guideline for stress and fatigue analysis of piping – (Doku Kennz.: B2/B/2.2/127a)

	Analysis of the mechanical behaviour, closed cooling water and service water systems			
	Pre-Konvoi "basically safe"[3]	**Konvoi K3 systems**[4]	**AdmV "K3 systems today"**	**BWR construction line 72**
Modelling pinciples	identical for K1 – K3	identical for K1 – K3	identical for K1 – K3	For TF and VE identical with AS1 and AS2
Rigidity of support structures	standard	determined by calculation (as-built classification)	determined by calculation (as-built classification)	RE-L 3052: standard, nominal-bore-specific values for "flexible", "normal" and "rigid"
System damping	D = 2 % for NB < 300 D = 3 % for NB ≥ 300	D = 2 % for NB < 300 D = 3 % for NB ≥ 300	D = 4 % for all NB in acc. with KTA 2201.4 [12]	RE-L 3052 (calculation acc. to Generic Specification on Basic Safety for piping): D = 2 % for NB < 300 D = 3 % for NB ≥ 300

One difference is the classification for the earthquake load case: loading level D for PWRs, loading level C for BWRs. As explained below, higher stresses were permissible on level D for the Konvoi plants than for the pre-Konvoi plants.

There are differences in the procedure for considering support structure rigidity values, but their repercussions cannot be assessed in general: For the verifications concerning the Konvoi plants, the "as-built" rigidity values were considered, whereas the pre-Konvoi plants and SWRs of construction line 72 were calculated using standard rigidity values. This fact means that the verifications of the Konvoi plants are more accurate.

A relevant, quantifiable difference exists in the consideration of the design stress intensity values. While the value for the piping of the pre-Konvoi plants, which is designed to be basically safe, was specified with $R_{mRT}/4$ and thus corresponds to the specifications of the K2 specifications for the test groups A2/A3, a value of $R_{mRT}/3$ or $R_{mT}/3$ was specified for the Konvoi plants in the K3 specifications and for the BWRs of construction line 72 in classification grade AS 3. This means that the load capacity of piping for which the AdmV in the case of the Konvoi plants only shows a maximum stress ratio of 75 % would already be 100 % exhausted if the verification had been carried out according to the specifications of the pre-Konvoi specifications on the basis of another design stress intensity value.

For earthquakes (loading level D), significantly higher stresses are permissible than for the other loading levels. With regard to the proof of integrity, the requirements of KTA 3211.2 [16] state that the limits of loading level D shall exclude a forced rupture. Here, it is accepted that plastic deformations may occur in larger areas. The affected component may require repair or replacement. MPA University of Stuttgart has compiled the requirements for the different power plant generations [3]. The following ensues for the closed cooling water and service water systems with consideration of the classification grades to be used as a basis according to the specification (giving, as explained in Chapter 5.1.2, only the derivation of the design stress intensity value from the tensile strength, as far as this is useful):

- Pre-Konvoi plants or KTA 3211.2: classification of earthquake as loading level D; permissible primary stress σ_{zul} (for all plants: membrane stress + bending stress considered) limited to 2.4 S with $S = R_{mRT}/4$, hence $\sigma_{zul} = 0.6\ R_{mRT}$.
- Konvoi plants: classification of earthquake as loading level D; permissible primary stress with application of the stress index method $\sigma_{zul} = \mathrm{Min}(3\ S,\ 2\ R_{p0,2T})$ with $S = R_{mRT}/3$. This results in a permissible stress of $\sigma_{zul} = R_{mRT}$.
- BWR construction line 72: classification of earthquake as loading level C; permissible primary stress $\sigma_{zul} = 1{,}8\ S$ with $S = R_{mRT}/3$ hence $\sigma_{zul} = 0.6\ R_{mRT}$.

This comparison shows that for the pre-Konvoi plants and BWRs of construction line 72, similar safety margins exist in the design against earthquakes, which are considered as the relevant dynamic load, regarding the maximum stress ratio for the closed cooling water and service water systems. Thus, the smaller pipe wall thicknesses in BWRs of construction line 72 have no adverse effects with regard to the earthquake load case. In the case of Konvoi plants, the safety margins required by the specification are smaller.

For the Konvoi plants, however, it has to be considered in this respect that enveloping floor response spectra were applied [18] in the seismic design inside the buildings of seismic class 1 (i.a. reactor building, emergency diesel generator building). Some site-specific areas of the service water system outside these buildings, however, were designed plant-specifically and differ in their seismic design. The safety margins mentioned below are not shown for plant-specific system areas.

For the KKI-2 and KKE plants, this results in clear safety margins in the seismic design of the closed cooling water and service water systems for the plant components in the buildings of seismic class 1 because at these sites significantly lower accelerations have to be considered than for GKN-2 [2]. According to [18], the accelerations according to the site-specific floor response spectra at these two sites amount to only 40 % of the acceleration values according to the Konvoi design spectra. For GKN-2 it is shown in [18] that in the lower room areas of the reactor building, which is where the majority of the closed cooling water and service water systems are located, there are also clear safety margins compared to the Konvoi design spectrum (accelerations between 49 % and 88 % of the design spectrum, depending on the direction of the acceleration). Even further up in the reactor building, where the surge tanks of the nuclear closed cooling water system are located, there are still safety margins available.

An evaluation of the maximum stress ratio of the closed cooling water and service water systems in GKN-2, which was submitted to the DKW Committee [19], shows maximum stress ratios up to a maximum of 40 % for the service water system at the locations considered. For the closed cooling water system, most of the results are also below 50 %. A value of 100 % maximum stress ratio is only shown in one location. According to the available documents, this maximum stress ratio occurs only once in the entire system, i.e. this value only occurs in one redundant system train. The calculations were performed using the Konvoi spectrum and, for the pipe diameters considered, with 3 % damping for the safe shutdown earthquake. According to the licensee, the highest maximum stress ratio in the closed cooling water system at GKN 2 is 75 %, based on the site-specific seismic spectrum. A maximum stress ratio greater than 50 % only occurred in three locations of the entire system.

5.1.3 Load cases

As explained in the previous section, the design of the closed cooling water and service water systems of the German nuclear power plants in operation took into account the loads resulting from operation and from external hazards, with the earthquake load case being the relevant load case.

In addition, the design of these plants also took into account the man-made external hazards from outside (blast wave and aircraft crash), based on requirements that correspond to those of the currently applicable regulations (SiAnf, BMI Guideline for the Protection of Nuclear Power Plants against Pressure Waves from Chemical Reactions). This was confirmed by the RSK within the framework of its safety review after Fukushima [2].

Regarding the requirements from the SiAnf [10], Section 2.1 (5) referred to in Section 4, the following can thus be stated:

The design of the closed cooling water and service water systems was based on the relevant impacts from internal and external hazards that correspond to those included in the present codes and standards. The systems were designed such that they will remain effective during and after such impacts.

5.1.4 Assessment of the safety margins

As explained in the section on the assessment criteria, the SiAnf require in Subsection 3.1 (2) a) justified safety allowances for the design of components depending on their safety-related significance. Recognised rules and standards can be applied to specific individual cases of application. This requirement is fulfilled for the closed cooling water and service water systems of all German nuclear power plants in operation. The design and the safety allowances applied here are based on recognised, partly conventional codes and standards and were reviewed in the licensing procedure.

It can be derived from the assessments in Section 5.1.1 that regarding the aspects 'materials' and 'manufacture', the design of the closed cooling water and service water systems in the plants in operation is adequate to also fulfil the higher-level requirements according to the RSK Guidelines, i.e. to exclude a catastrophic failure due to a manufacturing fault. In this context, the low internal pressure loading and temperature of the systems are also considered in the assessment.

Regarding the extent of the existing safety margins, the following can be stated: In Section 5.1.2, the dimensioning and analysis of the mechanical behaviour of the systems for the different plant generations was presented. The designs are different since the stresses in the pre-Konvoi systems were limited to lower values than in the Konvoi plants and in the BWR construction line 72 (here, with the exception of the earthquake load case). When evaluating this difference, a distinction has to be made between the different load cases:

- The closed cooling water and service water systems are physically separated and are operated at low pressures and temperatures. In case of plant-internal design basis accidents, no transients are to be expected that would exceed the expected operational loads. There is no design-related damage involving a loss of the integrity of the piping systems known to have occurred in operation.

- For the design basis earthquake, it is not possible to make recourse to any verification from operating experience. In this context, it is to be noted that, according to the specifications, higher stresses are permissible for the Konvoi plants than for the pre-Konvoi plants and for BWR construction line 72. In the case of the KKE and KKI-2 plants, additional safety margins exist for the plant components in the buildings of seismic class 1 since the design was for an enveloping seismic spectrum (Konvoi spectrum) that leads to higher accelerations and thus to higher loads on the components than in a plant-specific analysis for the earthquake to be assumed at the respective site. Due to the conservative design based on the enveloping Konvoi spectrum, significant safety margins also exist at the GKN-2 site.

  For all Konvoi plants, lower damping values (2 % and 3 %) were applied in the design than required today in the codes and standards (according to KTA 2201.4: 4 % damping).

For the plant-specifically designed components, the RSK has no information regarding the safety allowances available beyond the safety margins required in the specification.

When assessing the effects of the increased permissible stress intensity in Konvoi plants, it has to be taken into account that load redistributions due to plastic deformations occur in the piping systems when the loads exceed the elastic limits. As specified in Section 5.1.2 b), the requirements of the present codes and standards for loading level D allow for the possibility of plastic deformations. According to the specifications, no safety margins against plastic deformations are required with the stresses allowed for the Konvoi plants on level D. This procedure is also permissible according to the current codes and standards. Nevertheless, the calculation results available to the RSK show that the permissible stresses are not exhausted for the Konvoi plants.

The RSK has no knowledge that the safety margins in the closed cooling water and service water systems in the Konvoi plants may be insufficient. In connection with the explanations on the manufacture of the systems and on the load cases considered, it can thus in summary be confirmed that the requirements in Subsection 2.1 (13) of the SiAnf are fulfilled.

5.2 Operational monitoring, in-service inspections (ISI) and surveillance testing

Section 3.3 describes the measures for operational monitoring, in-service inspections (ISI) and surveillance testing of the closed cooling water and service water systems in the German nuclear power plants.

The assessment within the RSK Committee on PRESSURE-RETAINING COMPONENTS AND MATERIALS showed that a system of measures is implemented in the German plants to identify damage mechanisms in time. The effectiveness of these measures can be judged on the basis of operating experience.

German operating experience with essential service water systems (including the intercoolers) shows a large number of events involving pipes of small nominal bores (e.g. on branch pipes, drainage and vent lines, heat exchanger tubes). In individual cases, however, the more safety-relevant main piping of large nominal bores (NB > 400) was also affected by damage [21]. For closed cooling water systems, the number of events is significantly lower.

The pipe damage was mainly through-wall pitting damage caused by corrosion of the ferritic base material. In many cases, the corrosion attack was preceded by incipient damage, which was either suffered during the production process or was caused by external influences during operation. Typically, this was damage to coating. In some cases, this was additionally favoured by ageing effects. The most frequently observed corrosion mechanisms were shallow pit corrosion [22] and microbiologically induced corrosion [23].

In addition to incipient damage, the conditions in the local medium also contributed to the damage. Stagnating and highly turbulent media proved to be particularly unfavourable. In stagnant media, pollutants can sediment and lead to different oxygen contents on the inner surfaces of the pipes, thus creating the conditions for electrochemical corrosion processes. Depending on the water quality, microorganisms in the form of biofilms can also lead to corrosion. Highly turbulent flow conditions are mainly found in components with unfavourable flow path design and downstream of valves with throttling effect. The effect of the turbulence is initially shown by an erosive washout of the protective layers, followed by a planar wall thickness degradation in areas of exposed base material.

In addition to pipes, heat exchanger tubes of the nuclear intercoolers were also affected by damage, in case they were made of brass and not titanium. [21], [24]

The safety-related significance of the events affecting pipes as well as those affecting heat exchanger tubes was low in all cases. The damage to pipes was mainly revealed by minor leaks, which were mostly discovered during routine plant walk-downs and far less frequently during in-service inspections. There was no extensive damage that could have led to pipe failure. The damage had no direct influence on safe reactor operation and the availability of the service water system. No systematic differences between Konvoi and pre-Konvoi plants and BWR plants were found.

Operating experience shows that the measures for operational monitoring in connection with the in-service inspections are suitable for the timely detection of safety-relevant damage. In particular, there is no known case in which overlapping damage of several trains of the closed cooling water and service water systems would have resulted in an impairment of the system function. This statement also applies to the buried pipes.

5.3 Regulatory requirements

Section 3.4 lists the codes and standards to be applied for the closed cooling water and service water systems. It is clear from the presentation that higher-level requirements for system design are laid down in KTA 3301 and for seismic design in KTA 2201.4.

Regarding the requirements for the design as pressure-retaining systems, however, it has to be stated that the closed cooling water and service water systems are not included in the scope of the relevant safety standards of KTA 3211.

As concerns operational surveillance and in-service inspections, KTA 1403 contains requirements for ageing management that also have to be fulfilled for the closed cooling water and service water systems that are subject to preventive maintenance as components of group M2. However, KTA 3211.4, which is relevant regarding the in-service inspections of the external systems, excludes these systems from its scope of application, as do the other KTA Safety Standards of the 3211 series. There is an inconsistency in this KTA Safety Standard since the specifications of KTA 3211.4 contain requirements for systems exposed to river water or seawater that only apply to the service water systems.

In the SiAnf [10], too, the closed cooling water and service water systems are not counted among the external systems either, so that the requirements formulated in the SiAnf for the basic safety of the external systems do not apply to the closed cooling water and service water systems.

The higher-level requirements of the SiAnf with regard to the design, quality, manufacture and construction of the safety system are not supported by detailed requirements in the existing nuclear codes and standards for these systems.

Nevertheless, the review shows that the design of the existing systems is suitable to meet the higher-level requirements.

The need to supplement the regulations is discussed in Chapter 6, which provides a summary of the answers to the BMUB's questions.

5.4 Robustness

After the event at the Japanese Fukushima plant, the RSK found within the framework of the plant-specific safety review (RSK-SÜ) that, with regard to the seismic design of the German nuclear power plants, considerable safety margins existed in part. This assessment was made i.a. against the background of the conservative assumptions contained in the calculation chain and the knowledge about the seismic PSAs performed for individual plants in the past. The RSK considers the potential for reserves of one intensity level in comparison to the plant-specific earthquake determined according to the current state of the art in science and technology, basis: exceedance probability 10^{-5}/a (hereinafter referred to as current design-basis earthquake (*aktuelles Bemessungserdbeben* – BEBa)) [2].

In Section 5.1, the design boundary conditions for the closed cooling water and service water systems of the German nuclear power plants in operation were presented. These considerations show clearly that the Konvoi plants have lower safety margins regarding the earthquake load case involving the permissible stresses than the pre-Konvoi plants and the BWRs of construction line 72. However, the Konvoi plants also have safety margins from the design with respect to the loads arising during the design basis earthquake by using an enveloping design spectrum (Konvoi spectrum) that leads to higher accelerations in the reactor building than the plant-specific design spectra do, especially in the case of the KKI-2 and KKE plants.

For the further analysis of the safety margins of the German nuclear power plants, the RSK held talks in April 2019 with experts with extensive experience in plant construction and in the re-evaluation of piping systems in nuclear power plants [25]. In addition, the RSK evaluated further literature.

The main results of these talks and from the literature can be summarised as follows:

- To confirm the seismic design of the piping systems, specific tests were carried out by various institutions in Germany in the 1980s.
  During tests in the superheated-steam reactor (HDR) Großwelzheim, different pipe configurations were subjected to strong oscillating loads [26]. The KWU configuration withstood 800 % loading, i.e. eight times the design load.
  According to the BfS report [26], all design calculations proved to be conservative with regard to the piping stresses and the stresses acting on the supports. Overall, the report claims that the tests showed clearly that conventionally designed piping systems have considerable safety margins against seismic

loads, which may exceed the design loads many times, especially in the case of flexible support configurations.
The plant manufacturer has also carried out tests with piping systems under dynamic load [27]. The actual safety margins of the design could not be determined experimentally because of the limited loads that could be applied by the test equipment. However, it was possible to prove the capacity to withstand loads that would lead to 2.5 times the permissible loads in a linear analysis.

- In tests carried out in Japan, cracks due to fatigue effects (ratcheting) were found to form after multiple high loads that were several times the design loads [28]. At German sites, however, only short earthquakes with few load cycles are postulated. A failure of the piping due to such fatigue effects in the case of an earthquake load case can therefore be excluded.

- The simplified consideration of the soil-structure interaction also makes a major contribution to the existing design margins. The essential contribution to damping results from the radiation of energy from the structure into the environment (radiation or half-space damping). In the design of the German nuclear power plants, including the Konvoi plants, the damping due to the soil-structure interaction was considered in a conservative way.

- Both the calculations and the lessons learned from the tests show that the highest stresses are found on special fittings, especially T-junctions. This may also apply to inlet nozzles on vessels. In the calculation, the stresses at such points are determined with the stress index method, with which the stress increase at these discontinuity points is taken into account in an enveloping way by stress increase methods. More precise modelling with finite-element methods shows that the stress increase is lower and thus the permissible loads are significantly higher than those calculated with the stress index method.

- With regard to aftershocks, the assumption is that aftershocks are associated with lower loads than the main shocks. If plastic deformations have occurred during main shocks, the deformed system will subsequently behave elastically again, starting from the new state of equilibrium. Progressive plastic deformations therefore need not be postulated.

Overall, the experts were able to show in the technical discussion that there are considerable safety margins in the design of the piping systems in German nuclear power plants, including the Konvoi plants. These safety margins could be demonstrated especially in the experiments with piping systems under oscillating loads, where a multiple of the design loads could be safely withstood.

In the case of buried pipes, the experts do not believe that failure in the ground area is to be expected according to the available findings since the pipes follow the movements of the ground. The displacements that can occur at the point where these pipes enter the building must be taken into account. The construction is designed to absorb these displacements. Where necessary, suitable compensators are installed in the respective building areas.

All in all, the participants of the technical discussion came to the conclusion that, due to the considerable safety margins for the Konvoi plants, it can be confirmed that in case of an assumed earthquake with an intensity one level higher than the design earthquake (BEB+1), no failure of the piping systems will occur.

The RSK agrees with this statement, especially due to the high safety margins of the piping systems demonstrated in the experiments [26], but also considering the design characteristics presented in Chapter 5. The statement also applies to the pre-Konvoi plants and BWRs of construction line 72 since due to the limitation of the allowable stresses, these plants already have higher safety margins than the Konvoi plants, as has been explained in Section 5.1.

This statement is also in line with the results of a simplified earthquake PSA submitted in 2012 for the BWR of construction line 72 (see also the RSK Statement on the assessment of the implementation of RSK Recommendations following Fukushima [29]). The authorised expert consulted provided further information within the framework of the discussions among the RSK's DKW Committee.

The simplified earthquake PSA is based on a step-wise procedure. When experts performed a plant walkdown during the analysis, they found no obvious weak points with regard to the seismic design. The authorised expert consulted participated in selected parts of this walkdown. Subsequently, representative components likely to be subjected to seismic loads were selected and evaluated with regard to their probability of failure.

Within the framework of the review of the submitted earthquake PSA, the authorised expert consulted performed a deterministic examination of a targeted number of relevant component samples to see whether, on the basis of the existing seismic design for the intensity I = VII, safety margins could also be derived for an earthquake of the intensity I = VIII, so that an earthquake-induced failure need not be postulated for the intensity I = VIII. This scope of samples also comprised relevant components and system areas of the emergency core cooling and residual-heat removal chain, including the closed cooling water and service water systems (e.g. service water pump 32 VE20 D101, TF-intercooler 30 TF20 B101, piping 30 TH24 Z101/Z102/Z103).

The results of the above-mentioned investigations confirmed that in the case of an earthquake with an intensity of I = VII (BEB), an earthquake-induced failure of components required for accident control need not be postulated. Due to the existing safety margins, an earthquake-induced failure was not to be postulated even in the case of an earthquake with the intensity BEB+1.

Evaluations of damage to components in nuclear power plants after an earthquake indicate that the usual procedure with regard to the verification of seismic loads is conservative. For example, at the Japanese Kashiwazaki-Kariwa nuclear power plant [30] and the American North Anna plant [31], no comprehensive damage was observed on safety-relevant structures despite accelerations that were in part significantly higher than the design values.

All in all, what has been found for Konvoi plants as well as for BWRs of construction line 72 regarding the closed cooling water and service water systems confirms the conclusion from the RSK-SÜ that there are safety margins of at least one intensity level for these plants.

6 Answers to the questions posed by the BMUB

The following summarised answers to the questions of the BMUB are derived from the results of the discussions:

- Question 1: Are the existing regulatory requirements and/or the basic approach to the design and monitoring of the systems sufficient to ensure that the systems currently available in the plants can be operated with sufficient safety margins with regard to the aspects ‘operational monitoring’ and ‘load spectrum to be considered’ and that thus the higher-level requirements specified in the RSK Guidelines and Safety Requirements are fulfilled?

- Answer to Question 1:

  The procedure employed in the construction of the nuclear power plants in operation today was based on specifications of the plant manufacturer, which were reviewed in the licensing procedure. For the pre-Konvoi plants, the Generic Specification on Basic Safety was used as a basis, whereas the requirements for the Konvoi plants and BWR plants were less stringent.

  For all plants in operation, a load spectrum corresponding to the higher-level regulatory requirements was used as a basis. As concerns the materials, there are differences in the requirements with regard to toughness (required impact energy), but these are not relevant with regard to the mechanical requirements for the systems considered here.

  The safety margins for the plants of the Konvoi type and for BWR plants are reduced in accordance with the specifications by allowing higher equivalent stresses (one third of the tensile strength as opposed to one quarter of the tensile strength for pre-Konvoi plants). As regards the wall thicknesses of the piping of the Konvoi plants, however, this did not lead to any difference, as the evaluation of the piping actually used shows.

  In contrast, the wall thicknesses of the BWRs of construction line 72 are less for pipes with a large diameter (i.e. larger than 0.5 m). For the design basis earthquake, which represents the relevant dynamic load for these systems, the stresses are limited to values as those for the pre-Konvoi systems.

  What applies to all plants is that the closed cooling water and service water systems are operated at low temperatures and low pressures, i.e. they are low-energy systems for which a spontaneous failure or a significant crack growth due to the internal pressure need not be considered.

  Monitoring during production and during the construction of the plants was regulated for all plants by the specifications. In some individual points, the inspection frequency was lower in the case of the Konvoi plants and the BWR plants compared to the pre-Konvoi plants. However, operating experience has not yielded any indications of manufacture-related deficiencies in the systems that could be attributed to different levels of depth of inspection during manufacture.

Regarding operational monitoring and in-service inspections, no fundamental differences between the plants of different types can be found.

To sum up, it can be stated for all plants in power operation that the overall requirements specified in the RSK Guidelines and the Safety Requirements are fulfilled. This means that a catastrophic failure of the closed cooling water and service water systems due to manufacturing flaws can be excluded and that the systems were designed such that they will remain effective in case of any internal and external hazards.

Regarding the aspect of existing regulatory requirements in the BMUB's question, the following can be stated: Regarding the system requirements for the residual-heat removal systems, seismic design and ageing management, the current KTA Safety Standards include requirements that also apply to the closed cooling water and service water systems. As regards the design as pressure-retaining systems and the in-service inspections, the closed cooling water and service water systems are covered neither by the relevant KTA Safety Standards of the 3211 series nor by the detailed requirements in the SiAnf, since both the SiAnf and the KTA Safety Standards of the 3211 series do not include these systems in the scope of the “external systems”.

- Question 2: With regard to these two aspects, is there a need to formulate additional requirements, and if so, which ones?

- Answer to Question 2: Regarding the design of the closed cooling water and service water systems, a differentiation is required:

  - For the service water systems, the postulation in the KTA Safety Standards of a plant-specific approach to the design and the manufacture is still understandable from today's point of view. The design of these systems varies from plant to plant, depending on the local conditions, amongst other things on the properties of the cooling water and, in the case of buried piping, on the soil conditions. The Safety Standards of the KTA 3211 series are aimed in their entirety at mounted steel piping systems. In contrast, the buried parts of the service water systems in part involve the use of concrete piping. In view of the fact that no new nuclear power plants will be built in Germany, there is no need to extend the scope of the KTA 3211 series dealing with design and manufacture, i.e. Safety Standards KTA 3211.1 to 3, to the multitude of implemented designs. Any extension that would only concern a part of the plants would not adequately fulfil the purpose of a higher-level set of codes and standards.

  - In contrast, there are no site-specific differences in the layout of the closed cooling water systems. Therefore, the requirement in the KTA 3211 series for a plant-specific consideration is not comprehensible from a technical point of view. From a technical point of view, an extension of the scope of the Safety Standards of the KTA 3211 series would therefore be possible, but not necessary, as has already been shown for the service water systems. Against this background, an extension of the scope of the KTA Safety Standards regarding design and manufacture is not necessary.

Regarding in-service inspections and monitoring, this has to be judged differently, as requirements are made for the operation of the plants in service. The KTA Safety Standards do contain requirements for operational monitoring, but there is a need for further specification with respect to the application to closed cooling water and service water systems. KTA 3211.4 does not require the application to these systems.

The RSK therefore recommends extending the scope of application of KTA 3211.4 to the closed cooling water and service water systems. This was taken up in the last amendment procedure for KTA 3211.4, which has been concluded in the meantime. In this respect, this recommendation of the RSK has already been implemented.

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