Safety Standards

of the

Nuclear Safety Standards Commission (KTA)

KTA 3301 (2015-11)

Residual Heat Removal Systems of Light Water Reactors

(Nachwärmeabfuhrsysteme von Leichtwasserreaktoren)

The previous version of this safety standard was issued in 1984-11

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KTA SAFETY STANDARD

November 2015	**Residual Heat Removal Systems of Light Water Reactors**	KTA 3301

Previous version of the present safety standard: 1984-11 (BAnz No. 40a of February 27, 1985)

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Comments by the Editor:

Taking into account the meaning and usage of auxiliary verbs in the German language, in this translation the following agreements are effective:

shall	indicates a mandatory requirement,
shall basically	is used in the case of mandatory requirements to which specific exceptions (and only those!) are permitted. It is a requirement of the KTA that these exceptions - other than those in the case of shall normally - are specified in the text of the safety standard,
shall normally	indicates a requirement to which exceptions are allowed. However, exceptions used shall be substantiated during the licensing procedure,
should	indicates a recommendation or an example of good practice,
may	indicates an acceptable or permissible method within the scope of the present safety standard.

Basic Principles

(1) The safety standards of the Nuclear Safety Standards Commission (KTA) have the task of specifying those safety-related requirements which shall be met with regard to precautions to be taken in accordance with the state of science and technology against damage arising from the construction and operation of the plant (Sec. 7, para. (2), subpara. (3) Atomic Energy Act - AtG) in order to attain the protective goals specified in AtG and the Radiological Protection Ordinance (StrlSchV) and further detailed in the Safety Requirements for Nuclear Power Plants (SiAnf) and the SiAnf-Interpretations.

(2) The residual heat removal systems of light-water reactors (cf. **Appendix A**) comprise those systems that transfer heat from the reactor coolant and containment vessel to a heat sink whenever the operation-related main heat sink is not in use anymore. The residual heat removal systems (for short: “RHR-systems” in the following text) fulfill the following safety functions:

a) cooling of the fuel assemblies and removal of the stored energy,

b) replenishment of coolant to ensure the function of item a),

c) heat removal from the containment vessel.

(3) The present safety standard is essentially based on:

a) the Safety Requirements for Nuclear Power Plants (SiAnf) and

b) the SiAnf-Interpretations.

(4) The systems provided for the residual heat removal during design basis accidents are part of the safety system of the reactor plant. There is a close functional relationship between these systems and other safety equipment, in particular the reactor protection system and the power supply.

1 Scope

(1) This safety standard applies to the residual heat removal systems (“RHR-systems”) of nuclear power plants with light water reactors (pressurized and boiling water reactors, hereinafter referred to as "PWR" and "BWR", respectively). For the RHR-systems it comprises their

a) specified demand cases and required actions (Section 3),

b) design (Section 4),

c) system concept (Section 5),

d) physical arrangement and construction measures (Section 6),

e) operation and monitoring (Section 7),

f) power supply (Section 8),

g) assured functional capability and operational availability (Section 9),

h) reliability analyses (Section 10).

(2) The scope of this safety standard extends to the systems which are necessary after a reactor shutdown for the residual heat removal from the reactor coolant system and, if needed, from the containment vessel to a heat sink, in as far as the operation-related main heat sink is not in use for this purpose. In this context, certain parts of the primary and secondary coolant systems shall be considered as part of the RHR-systems if their function is required for these tasks.

(3) In accordance with their safety-related significance, the majority of components of the RHR-systems are part of the outer systems. However, subsections of the RHR-systems (e.g., their connecting parts toward the reactor pressure vessel) are correlated to the pressure-retaining boundary. The resulting requirements for these latter parts are detailed in SiAnf, Sec. 3.4, and in the safety standard series KTA 3201.1 through KTA 3201.4 and the safety standard series KTA 3205.1 through KTA 3205.3.

(4) The requirements in the present safety standard shall also apply to those parts of the auxiliary, supply and energy systems, the functions of which are necessary for the residual heat removal.

Note:

Examples of the systems within the scope of the present safety standard are listed in **Appendix A**.

(5) The present safety standard also contains requirements pertaining to other equipment in so far as those requirements are necessary to ensure the function of the RHR-systems (e.g., Section 6.2.1).

(6) Not subject to the present safety standard are:

a) the removal of residual heat from the fuel pool,

Note:

Removal of residual heat from the fuel pool is dealt with in safety standard KTA 3303.

b) the injection of boron to regulate the reactivity.

Note:

Injection of boron to regulate the reactivity is dealt with in safety standard KTA 3103.

(7) The assumption of design basis accidents necessary for the design of RHR-systems and the requirements regarding the proof of effectiveness of the emergency core cooling are dealt with in SiAnf, Sec. 3.3 and its Annexes 2 and 5. Additional requirements are contained in the SiAnf Interpretations.

2 Definitions

(1) Active component

An active component is a component which is externally operated or controlled and the function of which is activated either manually or automatically with the assistance of transfer and driving media (e.g., electrical current, hydraulic or pneumatic systems). Self-acting components (i.e., functioning without external power or controls) are considered as being active if the position of the respective component (e.g., safety valve or check valve) is changed in the course of its intended functional sequence.

(2) Failure

A failure is the loss of the ability of an equipment to fulfill the required function.

Note:

The event “**failure**” marks the transition from a correct to an erroneous action. A **malfunction** can occur simultaneously with a **failure**, but this is not necessarily so. For instance, an individual unit that is not yet demanded may have failed, however its malfunction will only become apparent in a demand case when it does not fulfill its function.

(3) Specified Normal Operation

The specified normal operation for which a plant, regarding its technical purpose, was designed and is suited, comprises the operating conditions and operating procedures

a) with its equipment in a functional condition (undisturbed operating condition, normal operation, Level of Defense 1),

b) of abnormal operation (disturbed operating condition, Level of Defense 2), and

c) during maintenance procedures (inspection, servicing, repairs).

(4) Single failure

A single failure is a failure which is assumed to occur in equipment during the specified demand case independently of the initiating event and which does not occur consequential to the demand case and was not known before the occurrence of the demand case. The single failure includes all subsequent failures resulting from this assumed single failure. A single failure is said to occur if a component of the equipment does not fulfill its function upon demand. An operation-related possible operating error that leads to a dysfunction is equated to a single failure. The single failure of a passive component equates to its malfunction.

Note:

The single failure concept is detailed in SiAnf, Annex 4.

(5) Operational availability

Operational availability is the condition of a system or part of a system (e.g., component, partial system, train), including any necessary auxiliary, supply and energy systems, during which the intended functions can be activated and are ensured to occur in case of demand.

Note:

Operational availability includes the functional capability.

(6) Functional capability

Functional capability is the ability of equipment to fulfill the intended task by performing corresponding mechanical, electrical or other functions.

Note:

The above-mentioned equipment includes, e.g., components, partial systems, trains as well as the necessary auxiliary, supply and energy systems.

(7) Main heat sink

The main heat sink serves to remove the waste heat occurring during electrical power production.

Note:

In nuclear power plants the main heat sink is the turbine condenser with its cooling system.

(8) Auxiliary measures

Auxiliary measures are manually initiated, anticipated, and in written operational regulations specified measures – possibly using operational systems – that have the goal of controlling and mitigating an event or positively influencing the sequence of an event. These measures shall be available specific to the event.

Note:

Auxiliary measures may be ones included in the operating manual or may be emergency measures.

(9) Maintenance

Maintenance encompasses the entirety of measures to maintain and restore the required condition as well as to determine and assess the actual condition (this includes inservice inspections). Maintenance is subdivided into preventive maintenance with its major elements of inspection and servicing, and the repairs.

(10) Pressure suppression pool

The pressure suppression pool is a spatially separated part of the safety enclosure. It serves, i.a., as receptor for the steam released from the pressure relief system, and as storage for coolant for the replenishment coolant to the reactor pressure vessel (BWR).

(11) Passive component

A component is considered to be passive if no operation is needed for it to function (e.g., pipes, vessels, heat exchangers). Automatic components (i.e., functioning without external power or controls) shall be considered as being passive if their setting is not changed within the framework of the intended functional sequence (e.g., safety valve or check valve).

(12) Redundant equipment

A redundant equipment is one which is equivalent to other devices of the system and can fulfill their function and which, if needed, can completely replace, or be replaced by, one of these other devices of the system.

(13) Redundancy

Redundancy is the availability of more operationally available devices than are needed for the fulfillment of the intended functions.

(14) Design-basis accident

A design-basis accident is an event or sequence of events the occurrence of which is not to be expected during the operating life of the plant, however, against which the plant must be designed such that the design principles, verification goals and verification criteria of the Level of Defense 3 are fulfilled, and upon the occurrence of which plant operation or any work in progress cannot be continued for safety-related reasons.

(15) Evaporation cooling facilities

Evaporation cooling facilities comprise natural-convection wet cooling towers and forced-convection cooling facilities (coolant cells).

(16) Heat sink

The heat sink is a medium (usually a water reservoir or the atmosphere) to which the residual heat is ultimately transferred.

(17) Primary heat sink

The primary heat sink is the one to which the decay energy as well as the waste heat from safety-related equipment during operation and accidents is ultimately transferred.

(18) Diverse heat sink

The diverse heat sink is one that, independent of the primary heat sink, is able to dissipate the decay energy as well as the waste heat from safety-related equipment during operation and accidents. Diversity concepts employ a heat sink different from the primary heat sink (e.g., air instead of water; wells instead of a river).

3 Specified Demand Cases and Required Actions

3.1 General Requirements

(1) In order to achieve the protective goal “Cooling of the Fuel Assemblies” the following is required:

a) ensuring the heat transfer from the fuel assemblies to the heat sink, and

b) ensuring a coolant inventory sufficient to cool the fuel assemblies by the replenishment from available storage tanks and by limiting the coolant losses.

(2) In this context, the functions specified in Section 3.2.2 shall be fulfilled at the different Levels of Defense.

3.2 Specified Demand Cases

3.2.1 Specified normal operation (Levels of Defense 1 and 2)

(1) In case of an interruption of the heat removal from the reactor to the main heat sink, the RHR-systems shall be able to cool down the shutdown reactor plant to a temperature

which allows handling of the fuel assemblies and shall be able to sustain the reactor at this temperature over a long period of time.

(2) The RHR-systems may also be used for other tasks, e.g., for flooding and draining procedures during fuel assembly handling. However, this may not inadmissibly affect the effectiveness of fulfilling the tasks specified under para. (1).

Note:

The coupling of operational and safety-related functions of the RHR-systems is dealt with in Section 5.1.2.

3.2.2 Design basis accidents (Level of Defense 3)

(1) The essential functions of heat removal out to the heat sink are:

a) heat removal from the reactor core,

b) heat removal from the secondary loop (PWR),

c) heat removal from the pressure suppression pool (BWR),

d) heat removal from the containment vessel.

(2) The heat removal functions specified under para. (1) require that the RHR-systems, in accordance with the respective operating, plant and system conditions, can ensure a sufficient coolant inventory and, as needed, secondary-loop water inventory. This includes:

a) replenishing the coolant,

b) supplying feedwater to the steam generators (PWR),

c) recirculating water from the sump,

d) limiting coolant loss.

(3) The functions specified under paras. (1) and (2) require that the integrity of the coolant-containing systems is ensured, especially by

a) limiting the pressure and temperature in the reactor coolant system,

b) limiting the pressure in the secondary loop (PWR),

c) protecting against overfeeding of the reactor coolant system,

d) limiting the filling level, pressure and temperature in the pressure suppression pool (BWR).

3.2.3 Internal and external events as well as very rare human induced external hazards

(1) The internal and external events as well as the very rare human induced external hazards specified in SiAnf, Annex 3, shall be considered.

(2) Even in the case of these events, the RHR-systems, under the respective operating, plant and system conditions, shall be able to fulfill the functions specified in Section 3.2.2, para. (1), items a), b) and c). In the case of very rare human induced external hazards, after 10 hours it is admissible to deploy auxiliary measures suited to the hazard.

Note:

The heat removal from the containment vessel (cf. Section 3.2.2, para. (1), item d)) does not need to be considered since these cases do not involve a coolant loss from the containment vessel.

4 Design

4.1 Boundary Conditions of the Heat Sink

(1) The boundary conditions dependent on the power plant site and the type of heat sink shall be taken into account.

Note:

These boundary conditions include, e.g., river water temperature, water level, humid-air temperature, biologic phenomena, water quality, ice build-up.

(2) In the case that heat is discharged into water bodies (direct cooling), in order to sustain the plant limit values during accidents, discharging the required amount of thermal energy shall be possible

a) at the highest expected cooling water intake temperature,

b) during low and high water, and

c) during the most unfavorable weather conditions.

(3) The design should be based on the highest expected cooling water intake temperature that was exceeded at the individual plant site in the immediately preceding ten years of observation on a total of no more than 28 days, or that temperature that must be expected based on the temperature forecast of a thermal load plan.

(4) In case the heat is discharged into the atmosphere via evaporation cooling facilities provided specifically for residual heat removal, the site-dependent fluctuation range of the wet bulb thermometer temperature shall be taken into account. The design should be based on the highest daytime wet bulb thermometer temperature reached on five days per year averaged over several years (≥ 10 a).

(5) To ensure the sufficiency of heat removal in case the afore-specified boundary conditions are possibly exceeded, suitable measures shall be provided (e.g., reduction of power to reduce the decay energy).

(6) Design analyses for the lowest service water temperature shall be carried out regarding:

a) stress-related loads of the components of the residual heat removal chains,

b) avoiding ice build-up (e.g., in the case of wet cooling towers).

4.2 Residual Heat Needed to be Removed

4.2.1 Contributing shares to the residual heat

(1) After shutdown of the power plant the following contributing shares to the residual heat may have to be considered:

a) decay energy of the fuel (cf. Section 4.2.2),

b) decay energy from activated structural materials and coolants,

Note:

The share of residual heat from item b) may be neglected in the design of RHR-systems because, in the case of light water reactors, after the reactor plant has been shut down this share of residual heat is insignificant compared to that from item a).

c) stored heat in the reactor coolant system – including the secondary side of the steam generators in case of a PWR – up to the first isolation device outside the containment vessel,

d) fission-product energy release caused by delayed neutrons,

Note:

This share of residual heat exists only briefly after an emergency shutdown.

e) heat of reaction from the zirconium-water reaction between the cladding tube material and the coolant,

Note:

This share of residual heat is significant only in the case of a loss-of-coolant accident and then only until completion of the reflooding of the core.

f) heat produced from operating the RHR-systems and their auxiliary and supply systems, including the electrical switch and distribution gear and the instrumentation and control equipment,

g) heat produced from operating the emergency power generating facilities, and

h) heat produced by the running reactor coolant pumps.

(2) The contributing shares of residual heat shall be considered in the design of the RHR-systems as listed in **Table 4-1** for the specified demand cases.

Specified Demand Cases		Contributing Shares of Residual Heat							
		a)	b)	c)	d)	e)	f)	g)	h)
Levels of Defense (LD) 1 and 2		x		x[1)]			x	x[2)]	x[3)]
LD 3	Accidents without loss-of-coolant	x		x[1)]	x		x	x[2)]	x[3)]
LD 3	Loss-of-coolant accidents	x		x	x	x	x	x[2)]	x[3)]
Internal and external events, very rare human induced external hazards		x		*x*[4)]	*x*		x	x[2)]	x[3)]

1) To be considered only when cooling down the reactor coolant system.

2) Can be waived if no emergency power case exists.

3) Can be waived if the reactor coolant pumps are switched off.

4) In case of very rare human induced external hazards after the stand-alone time of 10 h.

Table 4-1: Contributing shares of residual heat to be considered in the design of RHR-systems

(3) If the framework of the cooling concept allows still other cooling spots to be served by the RHR-systems (e.g., fuel pool), these cooling spots shall be taken into consideration.

4.2.2 Calculation of the decay energy of the fuel

(1) The decay energy shall be calculated in accordance with DIN 25463-1 and DIN 25463-2. In this context, the following margins of error shall be considered: for the residual heat removal after accidents (Level of Defense 3 during power operation) this margin shall be equal to two times the standard deviation (2 x sigma); in all other cases (Levels of Defense 1 and 2, Level of Defense 3 during zero-power operation, as well as internal and external events) this margin shall be equal to one times the standard deviation (1 x sigma). In the case of very rare human induced external hazards, no margin of error is required.

(2) The calculation of the decay energy after plant shutdown that is needed for the design of the RHR-systems shall be based on the following boundary conditions:

a) Basis for calculating the decay energy are the specifications of the admissible core loadings (general core specifications).

b) It shall be assumed that the power plant is operated at full power until shutdown. The duration of full-power operation before shutdown shall be assumed to be such that an equilibrium state of the nuclide vectors has been established that is representative for the entire fuel cycle.

Note:

The equilibrium state is usually reached after fifty days of power operation.

(3) For the residual heat removal during the accidents that are assumed to occur during power operation, the reference power assumed for calculating the decay energy shall be based on the maximum power that can be achieved during operation. This maximum power is assured by a reliably designed limitation of the reactor power (e.g., a process-variable limitation as specified in safety standard KTA 3501) plus the instrumentation and calibration errors. In all other cases, the calculation of the decay energy may be based on the nominal reactor power.

4.3 Specification of the Coolant Supply

4.3.1 Pressurized water reactor (PWR)

(1) The coolant supply needed for primary and secondary loop injection shall be specified taking the failure assumptions and redundancy requirements specified under Section 5.2 into account. The following shall, particularly, be considered:

a) Specified normal operation:

Flooding of the reactor compartment and the intermediate storage pool for refueling purposes.

b) Accidents with a loss-of-coolant:

ba) Flooding of the reactor core and transition to sump recirculation operation.

bb) Sufficient water cover at the sump intake device to avoid drawing in of air or steam by hollow-eddy formation and cavitation at the emergency pumps and residual heat removal pumps. When determining the required sump filling level, the most unfavorable possible combination of the following points shall be assumed:

bba) leakage location, leakage size and the available emergency cooling water supply,

bbb) retention of steam and water in plant and operating chambers under consideration of the dead volumes (e.g., reactor cavity),

bbc) water and condensate film on walls and ceilings as well as water puddles on horizontal surfaces,

bbd) inventory increase of primary circuit (e.g., by water injection, coolant temperature changes), and

bbe) additional pressure loss from clogged-up sump sieves considering the possible evaporation procedures due to a pressure reduction in deposits at the sump sieves that can lead to steam bubbles and hollow-eddies in the intake chamber.

bc) In the case of small leakages, it shall be possible to safely switch from the secondary-side to the primary-side heat removal.

bd) The overall volume, the coolant inventory and pressure level of the accumulators shall be specified based on the results from design calculations regarding the emergency core cooling.

c) Very rare human induced external hazards:

The water supply shall be sufficient for the removal of residual heat including the stored energy over a period of ten hours. When determining the necessary water supply, the water amount required for room and component cooling shall be considered. Regarding the follow-up mitigation of the event and the reactor shutdown, it shall be possible in due time to set up a sufficient water supply. This may involve the use of auxiliary measures.

(2) In order to ensure subcriticality, borated coolant shall be available for injection into the primary coolant system.

Note:

The requirements regarding coolant boronization are based on the reactivity balance for achieving a long-term, cold subcritical condition.

4.3.2 Boiling water reactor (BWR)

(1) The coolant supply in the pressure suppression pool of a boiling water reactor are determined by the design concept of the pressure suppression system and of the pressure relief system.

(2) Regarding a loss-of-coolant accident, a sufficient water cover shall be ensured at the sump intake devices (cf. Section 4.3.1, para. (1), item b), subitem bb)) in the control rod drive chamber and the pressure suppression pool in order to prevent hollow-eddy formation or cavitation at the emergency pumps and the residual heat removal pumps.

4.3.3 Water supply for the evaporation cooling facilities

In the case the heat is discharged into the atmosphere via evaporation cooling facilities specifically provided for residual heat removal, the water supply in the storage pools, together with the available water replenishment equipment, shall be dimensioned such that, considering the maximum evaporation losses, sufficient water amounts will be available in the specified demand cases for a long-term sustained functioning of the RHR-systems.

5 System Concept

5.1 System Function

5.1.1 Functionally suitable design of systems and components

(1) Considering the division into partial systems and their structure, the circuit design concept of RHR-systems shall account for the specified demand cases and the different respective functional requirements. The components required for this purpose shall be designed, constructed, fabricated and installed such that, considering the ambient conditions of the specified demand case, they will reliably fulfill the specified requirements. In addition, the requirements resulting from the radioactivity and the chemical composition of the cooling media as well as from the material properties shall be considered.

(2) Regarding the fulfillment of safety-related functions, the following aspects shall normally be considered:

a) The system structure and system functions shall normally be designed to be simple and have a clear layout.

b) The necessary components shall normally be designed and equipped such that they require the fewest possible auxiliary and supply systems for the control and mitigation of accidents.

(3) Regarding the fulfillment of their safety-related functions, the following aspects applying to the residual heat removing components shall normally be considered:

a) When determining the net positive suction head (NPSH) of the power plant in accordance with DIN EN ISO 17769-1, the containment vessel suction pumps designed for loss-of-coolant accidents shall be designed for the analytically determined temperature of the conveyed medium; this temperature value is available from pressure-buildup calculations of the containment vessel. The undercooling of the sump water due to the accident-related pressure increase in the containment vessel may not be taken into account when calculating the net positive suction head.

b) It shall be ensured that no media or foreign materials can accumulate in the heat exchangers that could inadmissibly affect the required heat transfer or integrity of the heat exchanger surface.

c) In case of a loss-of-coolant accident, the influx of motive gas from the accumulators into the primary circuit shall not lead to a situation where the needed heat transfer in the heat exchangers is not available anymore.

d) The components should be physically arranged in the primary circuit such that a natural convection can establish itself.

e) Sufficiently reliable pressure relief devices shall be provided that are able, in a controlled way, to reduce the reactor coolant pressure to the sufficiently low values necessary for a long-term residual heat removal. The transition to a long-term residual heat removal shall be carried out such that a sufficient residual heat removal is ensured at all points in time.

f) The accident analyses shall be used as the basis for determining the response and closing pressures, the opening and closing parameters and the blowdown capacities of the safety and relief valves for the primary (BWR) and secondary (PWR) coolant system, the physical state of the medium to be removed as well as for determining the physical conditions on the blow-off side.

5.1.2 Coupling of operation-related and safety-related functions

(1) During specified normal operation, residual heat removal may be carried out by systems with a purely operation-related function.

(2) It is allowable to cover the specified demand cases of specified normal operation, of design basis accidents, of internal and external events as well as of very rare human induced external hazards by the same RHR-system, provided, the requirements specified under Sections 5.2.2 and 5.2.3 are fulfilled.

(3) In as far as the RHR-systems intended for specified normal operation can control and mitigate a design basis accident, these systems shall normally be demanded prior to or together with the RHR-systems which are provided specifically for the control and mitigation of accidents. In this context, the function of the RHR-systems provided specifically for the control and mitigation of accidents shall not be detrimentally affected. Conversely, RHR-systems intended specifically for the control and mitigation of accidents may be used for operational purposes, provided, it is ensured that

a) in the case of accidents, these RHR-systems are transferred immediately, and with the aid of reliable equipment, into a circuitry condition that meets the safety-related requirements of the present safety standard,

b) the operation-related control signals do not detrimentally affect the safety-related functions, and

c) their operational use does not significantly influence the unavailability and failure probability of the residual heat removal under conditions of an accidents.

5.1.3 Coupling of different safety-related functions

(1) If different safety-related functions are coupled within a system (e.g., residual heat removal and ensuring long-term subcriticality) the effectiveness of each of these functions shall be ensured for the individually specified demand case.

(2) The reliability of the safety-related functions shall be ensured in the case of such a coupling.

5.2 Failure Assumptions and Redundancy Requirements

5.2.1 Single failure concept

The requirements specified in accordance with SiAnf, Annex 4, shall be applied.

5.2.2 Design basis accidents

5.2.2.1 Event combination and redundancy

(1) The design of the systems to be engaged in residual heat removal, including their auxiliary, supply and energy systems, shall be based on the following events which may occur simultaneously or at different moments in time:

a) The specified event to be controlled and mitigated:

The design basis shall be the functions specified under Section 3.2.2.

b) Accident-induced secondary failures:

The design basis shall be the consequences of accidents and secondary failures in those RHR-systems which are provided especially for the control and mitigation of accidents. A redundant equipment, the ineffectiveness of which must be assumed due to the accident, shall be excluded in the redundancy determination.

c) A single failure in any one component of the RHR-systems, however, under consideration of Section 5.2.2.2.

d) Secondary failures of a single failure:

Secondary failures of a single failure shall normally be considered to remain limited to that redundant equipment in which the single failure occurred (train-wise separation as specified under Section 5.2.2.4).

e) Maintenance measures:

The single failure criterion shall basically be also fulfilled during maintenance measures.

This entails that systems in which repair or maintenance measures that interrupt the operational availability of a train must be possible during power operation, that these systems shall basically be designed as doubly (n + 2) redundant (considering Section 5.2.2.3) with regard to the individually specified demand case. With regard to a functional test in another train, an additional redundancy is not required, provided, in the specified demand case, the operational availability of the train can be restored in due time.

Note:

"n" is the number of redundancies required for the control and mitigation of the event.

When planning maintenance measures for the shutdown reactor plant, the same requirements shall basically be fulfilled. However, under consideration of the temporal behavior of the reactor plant, fulfillment of the single failure criterion may take account of the fact that even in case of a single failure, the system function can reliably be restored in due time or that residual heat removal can be otherwise ensured.

(2) Failures that must be assumed to occur in the reactor protection system shall be dealt as specified in safety standard KTA 3501.

(3) The auxiliary and supply systems within a train (e.g., power supply, lubrication oil pumps, coolant valves of heat exchangers, hydraulic and pneumatic control equipment) shall normally be sufficiently reliable that they do not decisively influence the unavailability of residual heat removal after an accident.

5.2.2.2 Single failure of passive components

(1) A single failure need not be assumed for the passive components of RHR-systems, provided, the requirements regarding design, structure, choice of materials, manufacture and testability are fulfilled in accordance with specifications that account for the safety-related significance of the respective system parts.

Note:

Such specifications are, e.g., SiAnf, Annex 4, No. 2.5, as well as the safety standard series KTA 3211.

(2) In the case of RHR-system pipes that are smaller than or equal to DN 50 that do not meet the requirements under para. (1), a single failure shall be assumed only in the long-term phase of residual heat removal or sump recirculation operation.

5.2.2.3 Measures to be provided for the case of operational unavailability of redundant equipment

(1) In case of failure of an RHR-system component with a safety-related function, this component shall be repaired without delay after its failure is detected.

(2) If, in case of an operational unavailability of redundant equipment, the single-failure criterion can no longer be fulfilled in the remaining intact part of the system, the reactor plant operation shall be reduced upon detection of this condition (e.g., by power reduction or plant shutdown). If the nuclear power plant must be shut down, the shutdown condition shall be selected such that the operation-related main heat sink is maintained for as long as possible in order to avoid taking recourse to the systems weakened by the failure.

(3) The independent failure of a further redundancy need not be considered in case of the operational unavailability of a redundant equipment, provided, this failure – because of the short time necessary for the repair measure – has no decisive influence on the unavailability of residual heat removal after an accident.

5.2.2.4 Train separation

(1) Those RHR-systems, including the necessary auxiliary, supply and energy systems, that are provided for the specified demand case of a design basis accident, shall basically be constructed as separate trains. These trains shall be designed such that

a) each train can fulfill its safety-related function independent of failures in other trains, or

b) failures of components, which would cause the failure of more than one train, will be reliably controlled.

(2) Considering the basic requirement formulated in para. (1), interconnections of redundant trains and the mutual use of components are admissible, provided, all possible failures to be considered do not detrimentally affect the safety-related functions. Pipe line connections between redundant trains shall normally be closed off in their standby position and, in the case of safety-related demand cases, shall be able to be safely isolated.

Note:

Such pipe line connections may be the result, e.g., of the operation-related function of a system or of the connection to a mutually used test pipe. Connections may also be advisable in the interest of achieving a greater reliability, e.g., interconnecting certain components to increase the redundancy.

5.2.3 Common cause failures

(1) The following precautionary measures shall be taken against common cause failures which would have greater effects than the failure of a single train:

a) quality assured planning, design and construction of the systems and components in accordance with the functions to be fulfilled, taking all types of failures, secondary failures and ambient conditions to be considered into account,

b) train separation and spatial separation of the redundant equipment,

c) choice of suitable materials and fabrication procedures,

d) use of suitability-proven components (e.g., suitability test or proven service life),

e) testing under conditions as close as possible to those of the specified demand cases,

f) proper operation-related handling and servicing by trained personnel,

g) inservice inspections, and

h) quality assurance measures spanning from the planning stage to operation.

(2) In case service life or reliability analyses should indicate that the precaution measures taken against common cause failures are not sufficient despite fulfilling the requirements under para. (1), items a) through h), it shall be checked whether these precautions can be achieved by a diverse design of the equipment.

5.3 System-Internal Malfunctions and Leakages

(1) Malfunctions within the RHR-systems themselves shall be reliably controlled. The impacts on other safety equipment shall be limited to such an extent that their function is not inadmissibly affected.

(2) During operational shutdown procedures, a malfunction of pipes of the RHR-systems shall be assumed to occur in accordance with SiAnf, Annex 2, Enclosure 2, No. 4.2. The duration of use shall be assumed to be the length of time of operation with the pressures and temperatures in accordance to SiAnf, Annex 2, Appendix 2, No 4.2 (1) a). For a pipe failure in an RHR-system, the initial conditions to be assumed are those conditions of the reactor coolant at the time of normal operation when the transition to residual heat transfer by the RHR-systems is presumed to occur.

5.4 Safe Confinement of the Reactor Coolant

5.4.1 Reactor coolant confinement during specified normal operation

(1) Those parts of the RHR-system connected to the reactor coolant system, the admissible operating overpressure of which is lower than that of the primary coolant system, shall be fitted with automatic isolating equipment; this equipment shall consist of two series-connected valves; their valve seats shall be monitored for leak tightness.

(2) The coolant injection pipes shall normally be fitted with check valves which are self-acting regarding, both, their injecting as well as isolating functions.

(3) The isolation of the extraction pipes shall normally be designed to be performed with the same high degree of reliability as that of the injection pipes.

(4) The pressure retaining boundary of the reactor coolant, especially the parts outside of the containment vessel, shall meet high leak-tightness requirements even during the specified demand case of the RHR-system. It shall be possible to quickly identify and, if necessary, to isolate leaks.

5.4.2 Radioactivity barriers toward the heat sink

(1) The radioactivity discharged through the RHR-systems into the heat sink shall be strictly limited in accordance with StrlSchV.

(2) The cooling trains shall be monitored for leaks and radioactivity as specified in safety standard KTA 1504.

(3) Basically, two radioactivity barriers shall be provided.

Note:

Radioactivity barriers may be realized in the form of a cooling chain. The first barrier can be a passive component (heat exchanger), the second can be a second passive component or an appropriately graded of pressure level,

If under certain demand conditions only one barrier is available (e.g., when discharging steam from the steam generator into the atmosphere), the admissibility of this demand condition shall be demonstrated regarding the requirements in accordance with StrlSchV.

(4) Regarding steam generator tube leaks, precautionary measures shall be taken to limit leakage of coolant from the primary to the secondary side.

5.4.3 Isolation of pipes in case of a loss-of-coolant accident

(1) In system parts of RHR-systems with emergency cooling functions, the emergency cooling function shall be ensured to have top priority. Isolating devices shall be specified according to requirements of the emergency cooling function. No isolation devices in the containment vessel penetration of the coolant injection and extraction pipes of RHR-systems connected to the reactor coolant system are required, provided, separate isolation devices exist for the reactor coolant system that will reliably close upon a specified demand case and, provided, secondary damages between the reactor coolant system isolation device and the containment vessel can be ruled out.

(2) The pipe lines of RHR-systems which penetrate the containment vessel but are not required for maintaining the functions specified under Section 3.2.2, paras. (1) and (2), shall be closed off in a specified demand case. The closing device shall be designed in accordance with the pipe category specified in safety standard KTA 3404, Sec. 3.3, para. (1), item a), i.e., those pipes carrying reactor coolant. When specifying the closure times, the requirements both for confining radioactivity as well as for ensuring the residual heat removal function shall be considered. Deviating from safety standard KTA 3404, the tests and inspections shall be based on the respective requirements for the RHR-systems.

(3) Pipes without an emergency cooling function that are connected to the system parts of the RHR-systems outside of the containment vessel and which can contain accident-induced radioactively contaminated coolant shall be constructed such that they can be safely isolated by two series-connected shutoff devices placed as close as possible to the connecting points.

(4) Those parts of the primary-side RHR-systems with an open connection to the atmosphere outside of the containment vessel (e.g., the reflooding tanks or reflooding pools) shall be constructed such that they can be safely isolated from the accident-induced radioactively contaminated coolant by at least two series-connected shutoff devices.

6 Physical Arrangement and Construction Measures

6.1 General Aspects

6.1.1 Accessibility during specified normal operation

The measures required in this context are detailed in the GL-Planning of Radiological Protection.

6.1.2 Measures for preventing accident-related secondary failures

(1) Suitable measures shall be planned against the accident-induced loads to be considered (e.g., reaction, jet and missile forces, flooding and fire, shocks and pressure waves) and against changed ambient conditions (e.g. humidity, pressure, temperature, ionizing radiation). Such measures are, e.g.:

a) spatially separated physical arrangement of the redundant equipment,

b) construction measures (e.g., pipe whip restraints, covers, reinforcements, shock absorber),

c) structural measures, (e.g., compartmentalization, walls, raised foundations),

d) load-related design of the components,

(2) These measures shall also be applied to the auxiliary, supply and energy systems as well as to the instrumentation and control equipment of the RHR-systems.

6.1.3 Measures regarding long-term operation after accidents

By the physical arrangement of the RHR-systems and by the plant construction it shall be ensured, possibly by deploying auxiliary measures and considering the protection of personnel (e.g., heavy-duty breathing apparatus), that

a) the accessibility to failed system can be restored,

b) the water from flooded rooms can be pumped out, and

c) the leakages can be sealed,

in order to enable performing maintenance measures on the essential active components. The requirements in accordance with the guidelines GL-Planning of Radiological Protection, GL-Radiological Protection Measures and GL-Maintenance shall be observed.

Note:

Additional measures are specified in safety standard KTA 1301.1 (especially, Sec. 9.2.2) and safety standard KTA 1301.2.

6.1.4 Measures regarding external events and very rare human induced external hazards

Those RHR-systems, the function of which is necessary for the control and mitigation of these events, shall be designed for the respective loads. Spatial separation may be sufficient for their protection, provided, the respective loads are limited to partial areas of the power plant.

6.2 Containment Vessel Sump

6.2.1 General requirements

(1) The design of the containment vessel and its internals shall ensure that, in the case of a loss-of-coolant accident, the water escaping from the break is collected in a way that it can be re-introduced into the RHR-systems.

Note:

In case of a PWR, the re-introduction occurs via the containment vessel sump; in case of a BWR, the re-introduction occurs via the control rod drive chamber and the pressure suppression pool

(2) Dirt and debris in the containment vessel shall be kept as low as possible by proper choice of materials and design measures. In this context, the following aspects shall normally be considered:

a) insulating the pipes and vessels such that only insignificant amounts of the insulation material are set free,

b) use of insulation materials with a density distinctly different from that of water,

c) use of firmly adhesive and qualified paints on structural components,

d) use of erosion and corrosion resistant materials for those containment vessel internals that are in long-term contact with coolant.

(3) In case clogging-up of the sump sieves or of the retaining devices must be assumed, it is mandatory that a sufficient permeability is maintained. In this context, the following aspects shall normally be considered:

a) suitable water permeability of the insulation material used,

b) reduction of the hydraulic permeability due to the release of fiber and particle-shaped insulation materials as well as due to erosion and corrosion products,

c) chemical reactions of insulation materials due to accident conditions (e.g., change of porosity), and

d) creation of precipitants due to chemical reactions of materials inside the containment vessel with additives to the coolant.

6.2.2 Intake openings

(1) The flow paths to the intake openings in the RHR-systems shall be designed such that they can neither be damaged by debris nor obstructed by entrained materials to such degree that their functioning during long-term sump recirculation operation is inadmissibly affected.

(2) To ensure that the requirement under para. (1) is met, the following precautionary measures shall be taken:

a) Retaining devices shall be provided.

b) The surface area of the retaining devices shall be determined considering the possible accumulation of insulation materials, of dirt and debris and of chemical reaction products, such that the pressure drops over the retaining devices do not exceed specified design limits.

c) If more extreme pressure drops in the long term after a design basis accident cannot be ruled out, equipment and measures shall be held in readiness that are able to limit or reduce the pressure drops.

c) The retaining devices shall be designed such that the material not retained cannot inadmissibly affect the function of pumps, valves and heat exchangers and cannot obstruct the flow paths, especially those through the reactor core.

e) The intake openings shall be located sufficiently high above the floor level.

f) The retaining devices as well as the intake openings shall be protected against secondary failures (e.g., due to jet forces).

g) The retaining devices shall be designed such that the flow forces and differential pressures due to pressure equalization processes in the initial pressure release phase are accounted for.

h) The materials of the retaining devices shall be chosen such that, under accident conditions, no inadmissible weakening of the structures due to long-term erosion and corrosion will occur.

i) The intake openings shall be spatially separated.

j) The retaining devices and intake openings shall be designed such that they are accessible for inspections and for cleaning measures.

k) The gas release or vaporization processes caused by pressure drops at the deposits shall not lead to gas or steam contents at the intake side of pumps that would lead to an inadmissible decrease of the pumping rate or a damage of the pumps by cavitation.

6.2.3 Intake pipes

The intake pipes from the containment vessel sump to the first valve outside of the containment vessel shall be designed such that the possibility for water being lost under accident conditions can be excluded. For this purpose, precautionary technical measures shall be taken under consideration of the requirement specified in Section 5.2.2.2, para. (2).

6.3 Heat Sink (Equipment for a Heat Removal to the Environment)

6.3.1 General requirements

The equipment for the residual heat removal to a primary heat sink (e.g., the heat removal by discharging main steam into the atmosphere, the discharge of heat into bodies of water by means of direct cooling, the heat removal to the atmosphere via evaporation cooling facilities) shall be designed and physically arranged such that residual heat removal is ensured during specified normal operation, during accidents and in the case of the external events to be considered for the plant site (e.g. floods, drought, ice formation, washed-up flotsam, shell incrustation, earthquakes), and during very rare human induced external hazards (e.g., aircraft impact, gas-cloud explosion).

Note:

To control and mitigate postulated failures of the primary heat sink caused by failures in the region of the cooling water intake and cooling water return, a diverse heat sink is provided, the design of which must meet the requirements of emergency measures; these, however, are not within the scope of KTA safety standards.

6.3.2 Requirements for the design of water intake structures and the water flow paths in the service water system

(1) Intake structures, including the purification facilities as well as the cooling water inlet to the coolers, shall be designed to meet the respective redundancy requirements.

(2) In the case of a residual heat removal with river or sea water the following requirements shall be met:

a) Precautionary measures shall be taken to hold back flotsam, algae, hay, shells, or the like, and thus ensure the necessary intake of cooling water.
b) Freezing up shall be prevented and ice conditions shall be considered.
c) Unallowable backflow of the heated cooling water into the inlet of the cooling water shall be prevented.
d) In the case of navigable waters, the effects from ship accidents shall be considered.

(3) In the course of the water flow in the service cooling water system, operational measures preventing the formation of deposits (e.g., shell larvae) in the residual heat removing components shall be taken (e.g., heating the affected train, shock chlorination, mechanical cleaning).

6.3.3 Design requirements for the outfall structures and the water flow in the service cooling water system in case of river or sea water cooling

Outfall structures and the water flow in the service cooling water system shall be designed for the discharge of the cooling water into the primary heat sink during specified normal operation and in the case of accidents. In the case of malfunctions of the outfall structures or of equipment directing water flow in the service cooling water system caused by external events or by very rare human induced external hazards, it shall be possible to discharge the cooling water from the reactor plant through other ways without inadmissibly affecting the residual heat removal.

6.3.4 Design requirements for the evaporation cooling facilities

Evaporation cooling facilities for residual heat removal, including the associated water reservoirs, shall, in accordance with the respective redundancy requirements, be designed and physically arranged such that the following requirements are fulfilled in the specified demand cases:

a) Operation shall be ensured during frost (prevention of ice formation) in any of the specified demand cases, in particular by means of the corresponding physical arrangement of the storage pool and by other precautionary measures (e.g., by a graduated admission into, and ventilation of, the cooling cells, by heating the contact surfaces, by keeping the cooling tower internals free of snow).
b) Precautionary measures shall be taken against pollution and fouling by algae (e.g., by shock chlorination).
c) Evaporation losses shall be replenished whenever necessary.

6.3.5 Design requirements for the equipment to discharge main steam

In case of a failure of the main heat sink, it shall be possible, considering the available water supply, for the residual heat to be discharged in a controlled way to the atmosphere (PWR) or to the pressure suppression pool (BWR) until the residual heat removal chains can take over.

7 Operation and Monitoring

7.1 Specified Normal Operation (Levels of Defense 1 and 2)

7.1.1 Mode of operation

(1) A manual control of the RHR-systems is admissible. The controls may interact with individual components – individual actuation – and, in the case of functionally associated groups, they may interact with component groups - group actuation.

(2) Routine recurrent functional procedures should be automated in view of preventing operating errors.

(3) It shall be ensured by means of operational measures that the specified cooldown rate limits intended for the protection of the components of the reactor coolant system, as well as any other specifications to be considered (cf. Section 4), can be complied with during the shutdown procedure.

(4) The control elements for operating the RHR-systems shall be installed in the control room. The control elements for carrying out functional tests shall preferably be installed in the control room. Direct intervention in the mechanical components by onsite operating personnel shall normally be restricted to maintenance measures.

(5) In the case of failure of the station service power supply during residual heat removal, it shall be ensured that the components needed for residual heat removal can be supplied with emergency power and that the residual heat removal can resume without delay.

7.1.2 Monitoring

(1) Important parameters (e.g. pressure, temperature, flow rate, water level) as well as important valve settings shall be displayed or recorded in the control room such that the condition of the systems can be quickly and correctly identified. In the case of inadmissible deviations, hazard alarms shall be set off in the categories as specified in safety standard KTA 3501.

(2) To avoid radioactivity discharges, monitoring measures shall be provided as specified in safety standard KTA 1504.

(3) The as-specified water quality for the individual systems shall be monitored. Sampling points shall be physically arranged at representative locations.

Note:

Requirements regarding monitoring the boron concentration are specified in safety standard KTA 3103.

7.1.3 Precautionary measures

(1) All systems provided to control and mitigate accidents shall be monitored and kept in stand-by or operational mode for as long as accidents can be expected to occur. Generally, this requires that

a) the systems are filled with the coolants and auxiliary media required for their operation,

b) the necessary coolants are available in as-designed quantities and specified normal condition, and

c) the auxiliary media (e.g., lubricating oils) are available in the required quantities.

(2) In order to avoid inadmissible system conditions, equipment for the protection of components shall be installed and properly adjusted (e.g., safety valves, protective interlocks).

(3) Remotely actuated valves shall normally and as far as possible be in their stand-by position necessary for the control and mitigation of accidents. Incorrect positionings shall be displayed as alarms in the control room.

(4) Safety-related manually operated valves shall be secured against incorrect positioning.

(5) The containment vessel shall be kept clean regarding avoiding a possible clogging up of the retaining devices of the RHR-systems.

7.2 Design Basis Accidents ((Level of Defense 3)

7.2.1 Mode of operation

The RHR-systems shall be designed such that the residual heat can be removed using the following operational modes:

a) components functioning automatically without instrumentation and control equipment and without external power, solely as the direct influence of process sequences,

b) automatic activation and control,

c) when safety hazard alarms specified in safety standard KTA 3501 are activated: manual control from the control room or from local control stations. These manual interventions shall be specified in the operating manual.

d) manual control from the control room or from local control stations of the RHR-systems beginning 30 min after the accident occurs. These manual interventions shall be specified in the operating manual.

Note:

Manual control is also admissible earlier than 30 minutes, provided, analyses show that the accident sequence is not negatively affected, and the respective manual actions are specified in the operating manual.

7.2.2 Monitoring

(1) Important parameters essential for identifying the conditions of the systems (e.g. pressure, temperature, flow rate, filling level, pressure loss over the intake and sump sieves) as well as important valve settings shall be displayed or registered in the control room.

(2) The equipment required in this context shall be designed for the ambient conditions to be expected in case of an accident.

Note:

The design criteria for the instrumentation and control equipment for monitoring purposes are specified in greater detail in the safety standard KTA 3501.

7.3 Internal and external events and very rare human induced external hazards

7.3.1 Mode of operation

(1) The degree of automation of the RHR-systems shall be specified dependent on the protection concept of the power plant such that, in case of the internal and external events and the very rare human induced external hazards to be assumed, the reactor plant can be brought (from power operation) into the hot subcritical condition and can be maintained in this condition.

(2) Signals and actuations from the remote shutdown station and from that part of the reactor protection system designed for internal and external events and very rare human induced external hazards shall have priority over signals and actuations from those parts not designed for these events.

(3) The following applies to very rare human induced external hazards:

a) Regarding the possibility that neither the control room nor the remote shutdown station are operable or that neither can be manned within a short time, residual heat removal shall function automatically, i.e., without manual intervention, for at least 10 hours.

b) It shall be possible, as soon as personnel is again available, to start with the shutdown of the power plant; in this context, the actuation of components within the plant and the deployment of auxiliary measures is admissible.

7.3.2 Monitoring

(1) Important parameters essential for identifying the conditions of the systems (e.g. pressure, temperature, flow rate, filling level) as well as important valve settings shall be displayed or registered either in the control room or at the remote shutdown station in accordance with the concept for external events and for very rare human induced external hazards.

(2) The equipment required in this context shall be designed for the ambient conditions to be expected.

Note:

The design criteria for the instrumentation and control equipment for monitoring purposes are detailled in safety standard KTA 3501.

8 Energy Supply

8.1 Electrical Energy Supply

The supply of electrical energy for the RHR-systems shall be designed in accordance with the requirements specified in safety standard KTA 3701.

8.2 Non-Electrical Energy Supply

8.2.1 Directly coupled drives

In case diesel engines are used as directly coupled drives for pumps, they shall normally be designed, manufactured and operated as specified for emergency power generating facilities with diesel-generator units in safety standard KTA 3702.

Note:

Oher types of drives than diesel engines are possible (e.g., turbine-driven pumps).

8.2.2 Pneumatic and hydraulic power supplies

Basically, the same redundancy and reliability requirements shall be applied as for the other auxiliary and supply systems of the RHR-systems (cf. Section 5.2.2.1). However, if a failure of the pneumatic or hydraulic power supply results in a safe condition, a non-redundant design of the pneumatic or hydraulic power supply is sufficient.

9 Ensuring the Functional Capability and Operational Availability

9.1 Commissioning Tests and Inspections

9.1.1 Objective

The objective of the commissioning tests and inspections is to demonstrate the functional capability and operational availability of the RHR-systems and, thus, to fulfill one of the prerequisites for the commencement of the operation of the power plant. In addition, the results of the commissioning tests and inspections are the basis data for the inservice inspections.

9.1.2 Extent of the tests and inspections

(1) The following tests and inspections shall be carried out:

a) Functional tests of the individual units

Checking the functional capability and settings of the individual units and interlocks as well as their auxiliary, supply and energy systems.

b) Functional tests of the instrumentation and control equipment

Checking the interlocks, switch criteria, hazard alarms and functional sequences (e.g. selection, startup, shutdown, various modes of operation) based on the function descriptions or function diagrams.

c) Functional tests of the systems

Testing the function of the entire system. The tests shall be carried out such that the results enable drawing conclusions regarding the specified demand cases.

(2) If individual units fulfill several functions, each of these functions shall be tested individually.

9.1.3 Execution and documentation

(1) The requirements regarding commissioning as specified in safety standard KTA 1402, Sec. 5.4, shall be observed.

(2) During the individual testing steps specified under Section 9.1.2, the criteria and displays applied during the commissioning of the RHR-systems shall be checked and compared with the specified values. The execution of each test step and its results shall be documented.

9.2 Inservice inspections

9.2.1 Periodic functional tests

9.2.1.1 Objective

By means of periodic functional tests it shall be determined whether the tested components or the tested system are operationally available.

9.2.1.2 Requirements

(1) The systems shall basically be designed such that periodic functional tests can be carried out without restricting power operation. If this is not possible, it is admissible to test individual components at longer intervals, namely during plant shutdowns. The irrelevance to safety of these longer testing intervals shall be demonstrated in each individual case.

(2) The test shall not inadmissibly restrict the availability of the systems needed for the control and mitigation of accidents. Initiations from the reactor protection system shall have priority over the testing program.

(3) The periodic proof of operational availability shall normally, as far as this is possible without restricting operation, be carried out under similar conditions as those expected during an accident. The periodic functional tests, together with the earlier performed type, manufacturing and commissioning tests, shall enable drawing clear regarding the operational availability under accident conditions.

(4) The instrumentation, controls and power supply for the systems required for the control and mitigation of accidents shall normally be tested such that conclusions can be drawn on the operational availability of the systems.

(5) The signals from the reactor protection system may be simulated, provided, the requirements specified in safety standard KTA 3501 are observed.

(6) All parameters which help drawing conclusions on the operational availability of the components and systems shall be measured and documented.

9.2.1.3 Test intervals

The intervals between functional tests shall normally be specified according to the necessary reliability of the function (cf. Section 10). In this context, the technical conditions of performing the tests, the available data on failure rates and, as far as available, the manufacturer specifications shall be considered. Deviating test intervals deviating shall be well substantiated.

Note:

Experience has shown that a test interval of three to six weeks is optimal.

9.2.2 Non-destructive examinations

The RHR-systems shall be planned such that non-destructive examinations on the components specified in safety standard KTA 3211.4 can be performed.

9.3 Maintenance

Maintenance tasks shall be performed as specified in safety standard KTA 1402, Sec. 5.2.

10 Reliability Analyses

10.1 Objective

(1) In addition to deterministic design criteria, the design of RHR-systems should additionally be based on reliability analyses.

(2) Reliability analyses shall be applied to check the design of the RHR-systems considering the auxiliary, supply and energy systems using probabilistic methods and, thereby, to identify and evaluate possible weak points.

Note:

Within the framework of the Probabilistic Safety Analysis (PSA), the safety-related balance of necessary functions of the RHR-systems is evaluated relative to the safety level of the overall power plant.

(3) Reliability analyses supply quantitative data regarding the functional safety of the RHR-systems for the individually specified demand case.

(4) Reliability analyses also supply information regarding the influence of testing intervals and maintenance durations on reliability.

(5) In addition, reliability analyses may be performed with the following objectives:

a) deriving design requirements in those cases where either no deterministic criteria are available, or the available criteria are not sufficiently validated, or

b) providing quantitative information for the assessment of boundary conditions for the design.

10.2 Extent

Reliability analyses shall be performed for individually specified demand cases (e.g., failure of the main feedwater supply system, failure of the main heat sink, small leak in the reactor coolant system, large break in the reactor coolant system). In this context, the demand cases shall be selected such that, considering the occurrence probabilities and effectiveness conditions, the analyses cover all safety-related functions of the RHR-systems, including the necessary auxiliary, supply and energy systems.

10.3 Methodology

The methodology of the reliability analyses as part the probabilistic safety analyses is specified in the Periodic Safety Review Guidelines (PSR-GL) and the associated guidelines regarding methods and data.

10.4 Evaluation of the Results

(1) The evaluation of the results of the reliability analyses shall normally be based on:

a) the contributing factor of the RHR-system functions to the results of the Probabilistic Safety Analysis (PSA), specifically regarding the frequency of a core damage.
In this context, it shall be considered that the large number of functions of the RHR-systems also provide many of the functions needed for the control and mitigation of other events.

b) the safety level achieved in collaboration with the RHR-systems, specifically regarding the frequency of a core damage, considering the already achieved safety level.

Note:

Clear targets are also specified in INSAG-12

(2) The results of the reliability analyses shall normally be used for deriving improvement measures in case of detected weaknesses.

Note:

When evaluating the results of reliability analyses it shall be considered that

a) both the input data and the results are marked by statistical uncertainties,

b) a dominant part of the result is often contributed by common cause failures, especially in the case of very small values of the unavailability or failure probability, and

d) depending on the accuracy of the modeling of the event and fault trees, conservative boundary conditions are applied.

Appendix A

List of the Possible Systems within the Scope of the Present Safety Standard

Pressurized Water Reactor

a) Nuclear residual heat removal system consisting of

  aa) high-pressure coolant injection system for the injection of emergency coolant with the aid of safety injection pumps into the primary coolant system during the RHR phase via steam generators in case of a loss-of-coolant accident,

  ab) accumulators for the rapid reflooding of the reactor core in case of a loss-of-coolant accident,

  ac) low-pressure injection system or residual heat removal circuit for the injection of emergency coolant into the primary coolant system in case of a loss-of-coolant accident, and for the recirculation of the coolant via the residual heat exchanger, with the aid of the residual heat removal pumps in case of an accident and for operational demand cases,

b) Emergency feedwater system for feeding the steam generators,

c) Main steam safety and discharge control valve for the main steam blow-down from the steam generators,

d) Component cooling system for the removal of heat from heat exchangers for residual heat removal and from other components necessary for the functioning of RHR-systems, via intercoolers, and as a barrier in the cooling chain against the escape of radioactive substances into the environment,

e) Nuclear service cooling water system for cooling the intercoolers and other components necessary for the functioning of the RHR-systems, with heat discharged into bodies of water or the atmosphere,

f) Systems which ensure residual heat removal in the case of very rare human induced external hazards,

g) Auxiliary and supply systems the function of which is necessary for the RHR-system under consideration, in as far as design criteria and requirements for these systems are specified (e.g., power supply, controls, instrumentation, ventilation, structures).

Boiling Water Reactor

a) Nuclear residual heat removal system consisting of

  aa) high-pressure injection system for injection (of emergency coolant) into the reactor coolant system with the aid of the high-pressure pumps to replenish leakage losses and the steam discharged via the relief valves into the pressure suppression pool,

  ab) low-pressure injection system and residual heat removal circuit for the injection (of emergency coolant) into the reactor coolant system in case of a loss-of-coolant accident, for the recirculation of the coolant via the residual heat exchangers and for the cooling the pressure suppression pool with the aid of the residual heat removal pumps in the case of accidents and when required for operational demand cases,

b) Safety and relief valves for the pressure reduction and limitation in case of an accident by discharging the steam produced by residual heat into the pressure suppression pool,

c) Component cooling system for the removal of heat from heat exchangers for residual heat removal and from other components necessary for the functioning of RHR-systems, via intercoolers, and as a barrier in the cooling chain against the escape of radioactive substances into the environment,

d) Nuclear service cooling water system for cooling the intercoolers and other components necessary for the functioning of the RHR-systems, with heat discharged into bodies of water or the atmosphere,

e) Systems which ensure residual heat removal in the case of very rare human induced external hazards,

f) Auxiliary and supply systems the function of which is necessary for the RHR-system under consideration, in as far as design criteria and requirements for these systems are specified (e.g., power supply, controls, instrumentation, ventilation, structures).

The basic diagrams of **Figure A-1** and **Figure A-2** show examples of the residual heat removal systems presently realized in the Federal Republic of Germany. In each case only one of the redundant trains is depicted in the respective diagrams.

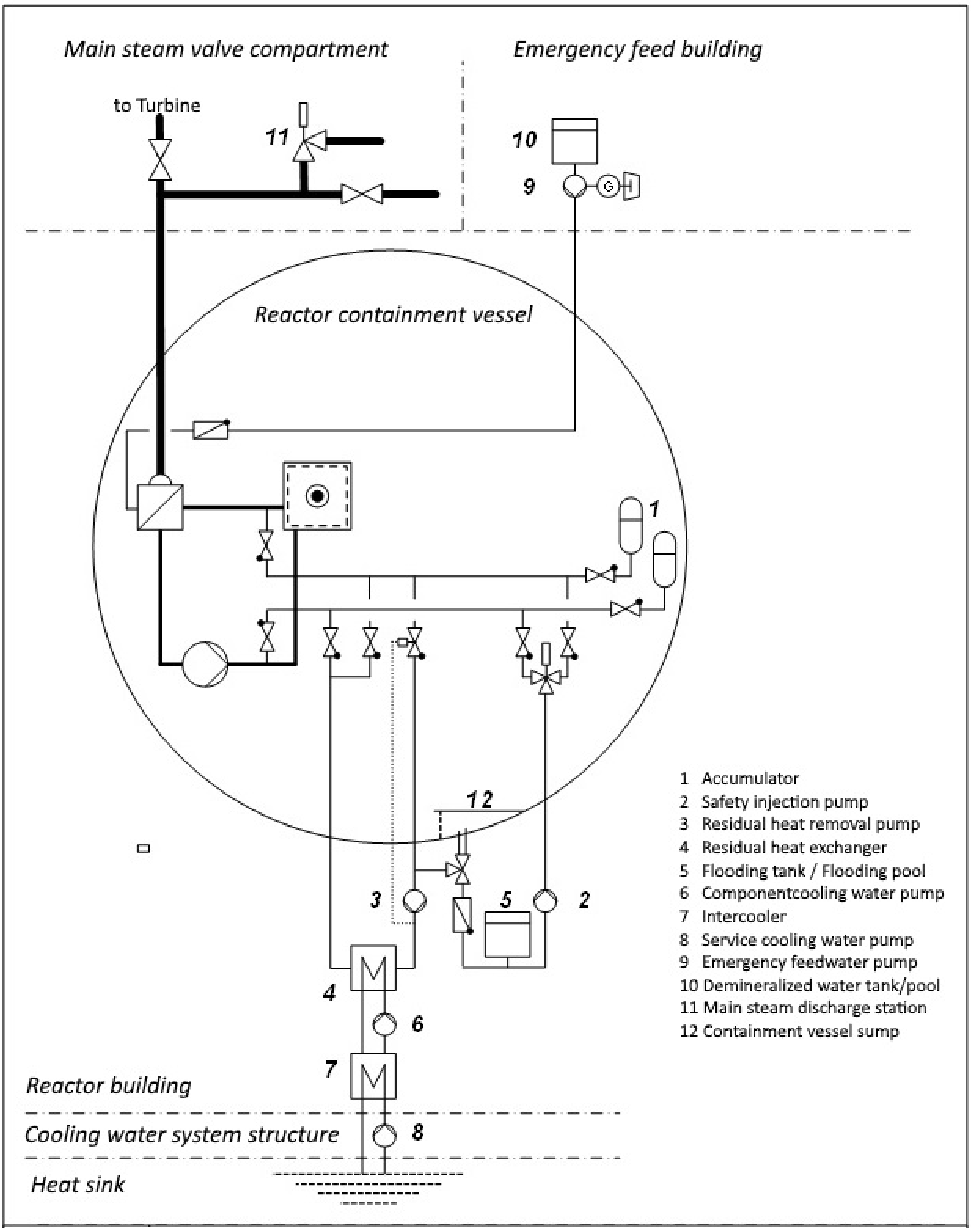

Figure A-1: Simplified diagram of the residual heat removal systems - Example 1 (PWR)

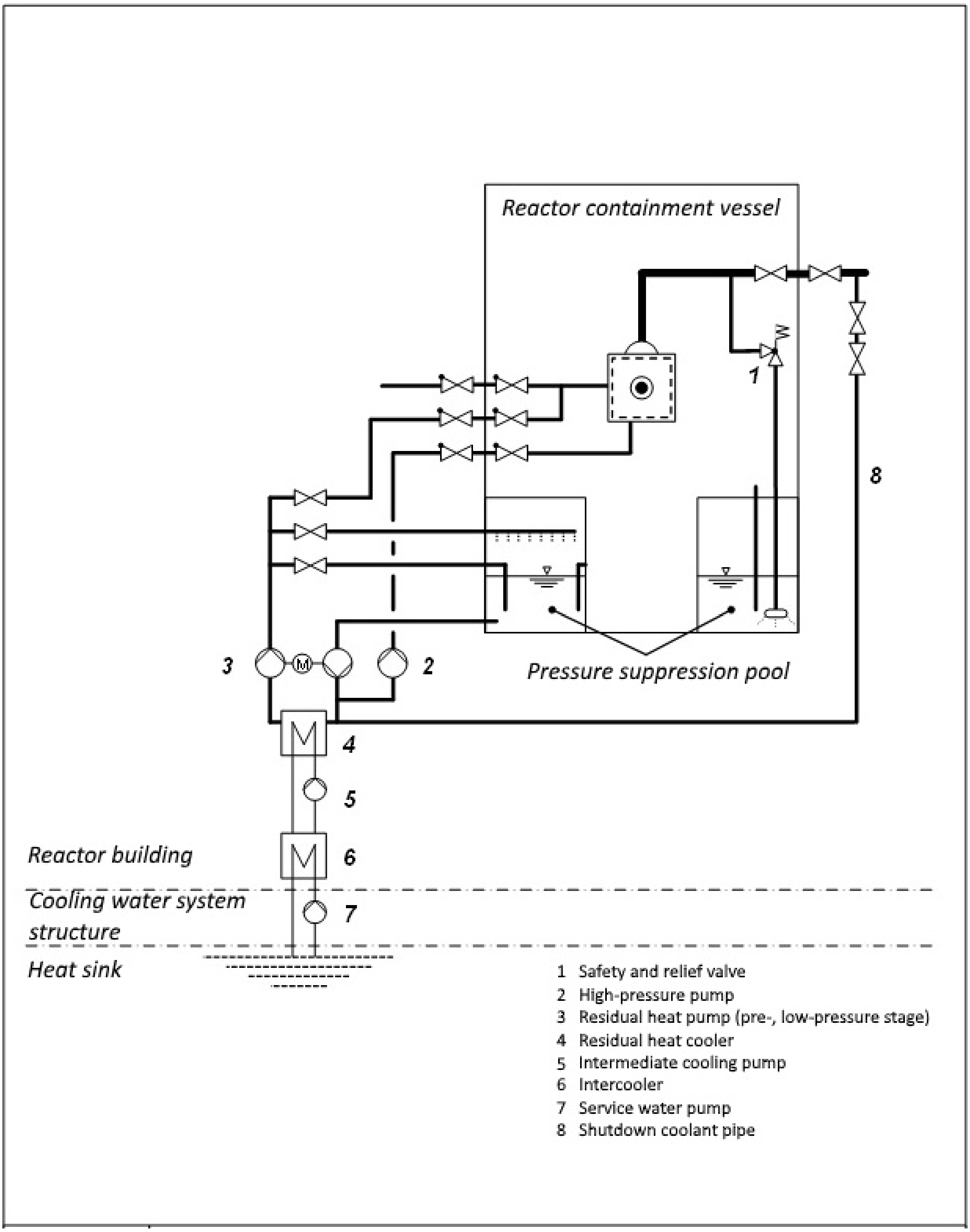

Figure A-2: Simplified Diagram of the Residual Heat Removal Systems, Example 2 (BWR)

Appendix B

Regulations Referred to in the Present Safety Standard

(Regulations referred to in the present safety standard are valid only in the versions cited below. Regulations which are referred to within these regulations are valid only in the version that was valid when the latter regulations were established or issued.)

AtG		Act on the peaceful utilization of atomic energy and the protection against its hazards (Atomic Energy Act – AtG) of December 23, 1959, revised version of July 15, 1985 (BGBl. I, p. 1565), most recently changed by Article 307 of the Act of August 31, 2015 (BGBl. I 2015, No. 35, p. 1474)
StrlSchV		Ordinance on the protection from damage by ionizing radiation (Radiological Protection Ordinance – StrlSchV) of July 20, 2001 (BGBl. I, p. 1714; 2002 I, p. 1459), most recently changed by Article 5 of the Act of December 11, 2014 (BGBl. I, p. 2010)
SiAnf	(2015-03)	Safety requirements for nuclear power plants of November 22, 2012, revised version of March 3, 2015 (BAnz AT of March 30, 2015 B2)
SiAnf-Interpretations	(2015-03)	Interpretations of the safety requirements for nuclear power plants of November 22, 2012, revised version of March 3, 2015 (BAnz AT of March 30, 2015 B3)
GL-PSR Basic Principles	(1997-08)	Guideline for the periodic safety review (PSR) of nuclear power plants in the Federal Republic of Germany – Basic principles of the periodic safety review August 18, 1997 – RS I 2 - 10120/9.0 (BAnz 1997, No. 232a)
GL-PSR Safety Status Analysis	(1997-08)	Guideline for the periodic safety review (PSR) of nuclear power plants in the Federal Republic of Germany – Safety status analysis August 18, 1997 – RS I 2 - 10120/9.0 (BAnz 1997, No. 232a)
GL-PSR Deterministic Safety Analysis	(1998-06)	Guideline for the periodic safety review (PSR) of nuclear power plants in the Federal Republic of Germany – Deterministic safety analysis June 25, 1998 – RS I 3 - 13151-6/10 (BAnz 1998, No. 153)
GL-PSR Probabilistic Safety Analysis	(2005-08)	Guideline for the periodic safety review (PSR) of nuclear power plants in the Federal Republic of Germany – Probabilistic safety analysis August 30, 2005 – RS I 3 - 10120/8.6 (BAnz 2005, No. 207)
GL-Planning of Radiological Protection	(1978-07)	Guideline for the Protection against Radiation of Personnel during the Execution of Maintenance Work in Nuclear Power Stations with Light Water Reactors: Part I: Precautionary Protective Measures to be taken during the Planning of the Plant - of July 10, 1978 (GMBl. 1978, No. 28, p. 418)
GL-Radiological Protection Measures	(2005-01)	Guideline for the Protection against Radiation of Personnel during the Execution of Maintenance Work in Nuclear Power Stations with Light Water Reactors: Part II: Radiological Protection Measures during Commissioning and Operation of the Plant – of January 17, 2005 (GMBl. 2005, No. 13, p. 258)
GL-Maintenance	(1978-06)	Guideline Relating to the Procedure for the Preparation and Implementation of Maintenance Work and Modifications at Nuclear Power Plants – of June 1, 1978 (GMBl. 1978, No. 22, p. 342))
KTA 1301.1	(2012-11)	Radiation protection considerations for plant personnel in the design and operation of nuclear power plants; Part 1: Design
KTA 1301.2	(2012-11)	Radiation protection considerations for plant personnel in the design and operation of nuclear power plants; Part 2: Operation
KTA 1402	(2012-11)	Integrated management systems for the safe operation of nuclear power plants
KTA 1504	(2015-11)	Monitoring and assessing the discharge of radioactive substances with water
KTA 3103	(2015-11)	Shutdown systems for light water reactors
KTA 3201.1	(1998-06)	Components of the reactor coolant pressure boundary of light water reactors; Part 1: Materials and product forms

KTA 3201.2	(2013-11)	Components of the reactor coolant pressure boundary of light water reactors; Part 2: Design and analysis
KTA 3201.3	(2007-11)	Components of the reactor coolant pressure boundary of light water reactors; Part 3: Manufacture
KTA 3201.4	(2010-11)	Components of the reactor coolant pressure boundary of light water reactors; Part 4: Inservice inspections and operational monitoring
KTA 3205.1	(2002-06)	Component support structures with non-integral connections; Part 1: Component support structures with non-integral connections for components of the reactor coolant pressure boundary of light water reactors
KTA 3205.2	(2015-11)	Component support structures with non-integral connections; Part 2: Component support structures with non-integral connections for pressure and activity-retaining components in systems outside the primary circuit
KTA 3205.3	(2006-11)	Component support structures with non-integral connections; Part 3: Series-production standard supports
KTA 3211.1	(2015-11)	Pressure and activity retaining components of systems outside the primary circuit; Part 1: Materials
KTA 3211.2	(2013-11)	Pressure and activity retaining components of systems outside the primary circuit; Part 2: Design and analysis
KTA 3211.3	(2012-11)	Pressure and activity retaining components of systems outside the primary circuit; Part 3: Manufacture
KTA 3211.4	(2013-11)	Pressure and activity retaining components of systems outside the primary circuit; Part 4: Inservice inspections and operational monitoring
KTA 3303	(2015-11)	Heat removal systems for fuel assembly storage pools in nuclear power plants with light water reactors
KTA 3404	(2013-11)	Isolation of operating system pipes penetrating the containment vessel in the case of a release of radioactive substances into the containment vessel of nuclear power plants
KTA 3501	(2015-11)	Reactor protection system and monitoring equipment of the safety system
KTA 3701	(2014-11)	General requirements for the electrical power supply in nuclear power plants
KTA 3702	(2014-11)	Emergency power generating facilities with diesel-generator units in nuclear power plants
DIN EN ISO 17769-1	(2012-11)	Liquid pumps and installation - General terms, definitions, quantities, letter symbols and units - Part 1: Liquid pumps (ISO 17769-1:2012); Trilingual version EN ISO 17769-1:2012
DIN 25463-1	(2014-02)	Calculation of the decay power in nuclear fuels of light water reactors - Part 1: Uranium oxide nuclear fuel for pressurized water reactors
DIN 25463-2	(2014-02)	Calculation of the decay power in nuclear fuels of light water reactors - Part 2: Mixed-uranium-plutonium oxide (MOX) nuclear fuel for pressurized water reactors
INSAG-12	(1999-10)	Basic safety principles for nuclear power plants – 75-INSAG-3 Rev. 1