

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

If there is any doubt regarding the information contained in this translation, the German wording shall apply.

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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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PLEASE NOTE: Only the original German version of this safety standard represents the joint resolution of the 35-member Nuclear Safety Standards Commission (Kerntechnischer Ausschuss, KTA). The German version was made public in the Federal Gazette (Bundesanzeiger) on January 8th, 2016. Copies of the German versions of the KTA safety standards may be mail-ordered through the Wolters Kluwer Deutschland GmbH (info@wolterskluwer.de). Downloads of the English translations are available at the KTA website (<http://www.kta-gs.de>).

All questions regarding this English translation should please be directed to the KTA office:

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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.e., 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 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