Safety Standards

of the
Nuclear Safety Standards Commission (KTA)

KTA 3413 (2016-11)

Determination of Loads for the Design of a Full Pressure Containment Vessel against Plant-internal Incidents

(Ermittlung der Belastungen für die Auslegung des Volldrucksicherheitsbehälters gegen Störfälle innerhalb der Anlage)

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KTA SAFETY STANDARD

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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 this 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) In the Safety Requirements for Nuclear Power Plants the following requirements are layed down, that serve as design bases of the containment vessels

a) According to SiAnf No. 2.2 para. (1) and (4) the confinement of the radioactive materials present inside the nuclear power plant shall be ensured by sequential barriers and retention functions. In order to fulfil the radiological safety objectives on level of defence 3 the barrier given by the containment shall maintain its effectiveness.

b) According to SiAnf No. 3.6 para. (1) the nuclear power plant shall contain a retention system, consisting out of the containment and additional related systems. Under the operating conditions in which it is closed according to schedule, the containment shall fulfil its safety functions on levels of defence 1 to 3.

The respective design of the containment vessel itself is provided for in KTA 3401.2. In that safety standard, the loading conditions on which design, construction and calculation have to be based are classified and specified by characteristic loads (e.g. dead weight, pressure, temperature, force, etc.). This safety standard specifies the assumptions and procedures for the determination of the loads which are dependent on location and time.

(3) For the determination of the loads resulting from incidents, leaks in piping are postulated which have a cross-section up to 2A and lead to the maximum stresses which act upon the containment vessel and, thus, determine its design. The water-steam mixture escaping through these leaks leads to pressure and temperature loads which act upon the containment vessel. Depending on the location of the respective leak, these loads may act upon different areas of the containment vessel. Furthermore, the flow forces may act upon the containment vessel, either direct or through their reaction forces. The malfunction of ventilation systems may also lead to loads acting upon the containment vessel; these are similar to those occurring during loss-of-coolant accidents and are therefore also included in this safety standard.

(4) Depending on the kind of problem posed, the major physical processes in the case of postulated events are simulated by analytical models and compiled in computer codes. if possible, detailed specifications are avoided in both the models and the computer codes in order to be able to take into account the further development of the state of the art. This safety standard also specifies allowances in order to counteract uncertainties in calculations or deviations between calculatory assumptions and actual construction. Moreover, boundary conditions and assumptions are prescribed.

(5) The relationship between incidents and the resulting loads acting upon the containment vessel is presented in **Fig. G-1**.

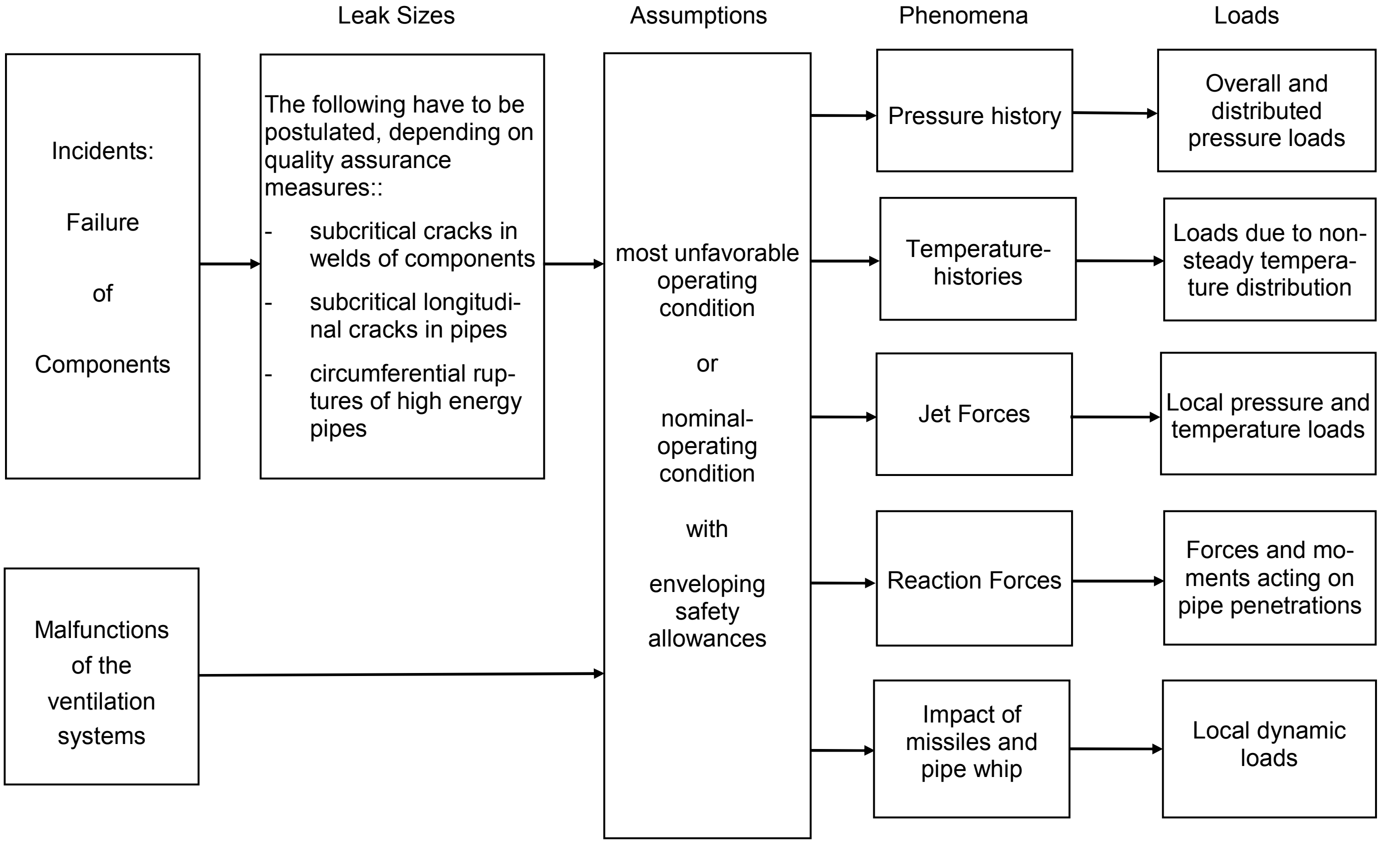

Fig. G-1: Relationship between incidents and resulting loads acting upon the containment vessel

1 Scope

This safety standard applies to the determination of loads for the design of a full pressure steel containment vessel for water-cooled reactors, including the nozzle and airlocks permanently linked to this containment vessel hereinafter referred to as containment vessel against incidents caused by losses of coolant inside the plant. This safety standard also applies to the determination of loads which may result from a malfunction of the ventilation system. Theme loads are associated with the following loading conditions in accordance with KTA 3401.2t

a) design loading condition with design basis overpressure ("DF 1”),

b) design loading condition with design basis underpressure ("DF 2"),

c) loss-of-coolant incident with pressure and temperature histories including possible jet and reaction forces (“ST 1”),

d) pipe rupture inside the containment vessel ("ST 4”),

e) pipe rupture outside the containment vessel ("ST 5"),

f) occurrences resulting in underpressure inside the containment vessel: breakdown of ventilation system, occurrences near the end of loss-of-coolant incidents and small leaks ("ST 2").

The determination of the loads for the design of internal structures of the containment vessel is not included in this safety standard.

2 Definitions

(1) component

A component is a part of a system which is delineated in accordance with structural or functional aspects.

Note:

A component is still capable of performing part functions.

(2) Reaction force

A reaction force in a force caused by the transient or stationary escape of a fluid from an opening of a pressurized component and acting upon and further transmitted by the latter.

Note:

The forces generated in a system of pipes by transient flow processes will also act as reaction forces.

(3) Jet force

A jet force is a force which is caused by a free jet of a fluid (liquid, steam or mixture of the two) escaping through an opening and which is transmitted from the fluid to the components, systems or structures exposed to said free jet.

(4) Full pressure containment vessel

A full pressure containment vessel contains the non-isolatable parts of the primary system, including the secondary system up to the first isolation valves and absorbs the mass and energy release from these systems without any direct precipitation of the escaping steam.

3 Types of Loads

(1) The time histories of pressures, temperatures and forces shall be established for each incident which determines the design of the containment vessel.

(2) In this context, the following shall be distinguished:

a) overall loads acting uniformly on all the areas of the wall of the containment vessel,

b) distributed loads acting non-uniformly on different areas of the wall of the containment vessel, and

c) local loads acting only on locally confined small areas of the wall of the containment vessel.

It shall be recognized that different incidents may determine the design loads as contributed by overall, distributed, or local loads.

4 Loads to be Determined

4.1 Overall Loads

4.1.1 Overall Overpressure

The possible maximum pressure and temperature increase in the atmosphere as a result of the mass and energy release shall be determined for the leak sizes to be postulated on pressurized components inside or outside the containment vessel.

4.1.2 Slight Vacuum or External overpressure

The maximum external pressure load acting on the containment vessel an a result of a decrease of the partial pressure of the air inside the containment vessel, or as a result of malfunctions of the ventilation system, shall be determined.

Note:

A decrease of the partial pressure of the air may occur an a result of leakages in the case of a continued simultaneous operation of the vacuum pressure system.

4.2 Distributed Loads

4.2.1 Pressure Loads

The pressures acting non-uniformly on different areas of the wall of the containment vessel during pressure equalization processes inside or outside the containment vessel shall be determined.

4.2.2 Temperature Distribution

The tangential temperature distribution in the wall of the containment vessel which in most unfavorable for the loads acting on the containment vessel and which in due to different temperature influences between insulated and noninsulated wall areas (e.g. restraint zone), wall thickness changes and different flow impacts in the case of pressure equalization processes shall be determined.

4.2.3 Pressure Waves

Pressure waves in the atmosphere which are caused by internal or external events and act on the wall of the containment vessel need not be taken into consideration.

4.3 Local Loads

4.3.1 Jet Forces

(1) Those components shall be specified whose failure may result in loads in the form of jet forces acting on the containment vessel.

(2) Jet forces including the pressure distribution over the area of incidence and the temperature in the area of incidence shall be determined.

4.3.2 Reaction Forces

(1) The effects of the dynamic forces and moments shall be determined as they are transmitted via a broken pipe train to

the associated pipe penetration through the containment vessel.

(2) If instationary flow processes, such as they may result from a quick closing or opening of valves, have to be considered as loads determining the design of a plant, the time histories of the resulting reaction forces and moments acting on the associated penetration through the containment vessel shall be determined.

4.3.3 Missiles and Whipping Pipes

If the impact of missiles and whipping pipes on the wall of the containment vessel cannot be ruled out, their masses, dimensions, velocities and angles of incidence shall be determined.

5 Methods of Calculation

5.1 Mathematical Models

5.1.1 Overall Loads

5.1.1.1 Overall overpressure

(1) For the calculation of the pressure and temperature buildup in the containment vessel, modeling should use a simple nodalization (i.e. subdivision of an overall compartment into subcompartments).

Note:

Experience shown that calculations using simple nodalizations, as compared with those using more refined nodalizations, lead to conservative results.

(2) The emission of heat to parts such as walls, components or grids may only be taken into account if use is made either of the heat transfer correlations in accordance with Appendix A or of data which have been confirmed as far as their transferability is concerned. For the calculation of the heat flux, the structures shall be subdivided in accordance with Appendix B. with respect to the thermal insulation effect of lacquer paints, if any, the upper tolerance limit of thickness and the lower tolerance limit of thermal conductivity shall be used.

(3) Thermal imbalances between sump water and air-steam mixtures shall be considered either in the models or in accordance with Section 6.1.

5.1.1.2 Slight Vacuum or External Overpressure

(1) For the determination of the possible maximum Pressure decrease in the containment vessel as a result of a reduction of the partial pressure of the air inside the containment vessel (see Section 4.1 (2)), the emission of heat to the parts which is employed shall be as large as possible. In this context, the values used for the heat transfer correlations shall be either four times the values specified in Appendix A or data which have been confirmed as far as their transferability in concerned. With respect to the thermal input effect of lacquer paints, if any, the lower tolerance limit of thickness and the upper tolerance limit of thermal conductivity shall be used. An far as the mixing between leak steam and air is concerned, models shall be used which consider the mixing of leak steam and air in such a way that the resulting value of pressure is as small as possible. Without any further demonstration, a piston model may be used which only displaces air from the containment vessel.

(2) When calculating the pressure buildup in the annulus, the annulus ventilation system may only be taken into consideration if it can be demonstrated to operate at the capacity postulated during the incident. The nodalization shall be laid down in accordance with the spatial conditions for heat distraction from the atmosphere of the annulus and with the effect of the annulus ventilation system.

(3) Basically, the zero discharge heads of the fans shall be used for the determination of the maximum differential pressure between the atmosphere of the annulus and the atmosphere of the containment vessel in the case of ventilation system malfunctions. Deviations from this procedure may be permitted if safety features are provided for the limitation of the maximum differential pressure.

5.1.2 Distributed Loads

(1) Leaks which lead to an enveloping unsymmetrical load on the containment vessel because of the prevailing spatial conditions shall be specified and investigated per component and location. For the determination of this load, and in view of the pressure buildup in the wall area of the containment vessel, a nodalization shall be used which is suited to cover overflow processes between the individual compartments inside and outside the containment vessel, water transport and water separation processes, and heat emission to parts in accordance with Section 5.1.1.1 (2); in this context, the values quoted for αstag shall be used if Appendix A is employed.

(2) As far as the cases specified in Section 4.2.2 are concerned, calculations of the local and temporal pressure and temperature histories in the atmosphere of the containment vessel and the annulus and in the wall of the containment vessel shall be carried out as a matter of principle. For the determination of the heat transfer coefficient, the same procedure as used in Section 5.1.1.2 (1) shall be followed; in this context, 4 times the values quoted for α_{stag} shall be used if Appendix A is employed. The thermal insulation effect of coats of lacquer may only be used if their resistance under incident conditions has been demonstrated. Simplifying and, as far as distributed loads are concerned, enveloping calculations are admissible.

5.1.3 Local Loads

5.1.3.1 Jet Forces

(1) For the determination of the jet forces, the blowdown models and computer codes and their associated boundary conditions and assumptions shall be selected in such a way that the highest jet forces can be demonstrated to result for the individual leak locations.

(2) For the determination of impact areas and of the pressure distributions prevailing in these areas, only empirically confirmed models may be used; in this context, attention shall be paid to the limits due to measuring errors and to the respective validity margins.

(3) For the determination of the temperature of the jet in its area of impact, the prevailing thermodynamic conditions shall be taken into consideration.

5.1.3.2 Reaction Forces

(1) Reaction forces shall be calculated applying the laws of the conservation of mass, energy and momentum and considering the thermodynamic equations of state.

(2) The calculation of the reaction forces having repercussions upon the containment vessel shall be based on the leak location resulting in the largest loads, such as the moment or force loads. The following cases shall be distinguished:

a) Leaks which, because of their size, lead to minor repercussions on the system pressure, and larger leaks which have to be assumed to open slowly; the determination of the force which applies at the location of the leak shall be based on the difference between the initial pressure of the fluid and the ambient pressure and on either the clear cross section of the pipe or that of the leak as area of impact. In the case of circumferential ruptures, the application of the pressure prevailing in the mouth of the leak on the pipe wall cross-section shall also be taken into consideration.

b) Leaks which, because of their size, lead to major repercussions on the system pressure: deviating from case (a) above, the determination of the force which applies at the location of the leak may be based on the temporal variation of the initial pressure. In addition, dynamic effects in the form of pressure waves in the fluid which have been caused by the leak opening process shall be taken into consideration.

(3) If instationary flow processes, e.g. as a result of a quick closing or opening of valves, may also have to be considered as loads determining the design, the time histories of the resulting reaction forces and moments shall be determined. The calculation shall be based on the initial states in terms of pressure, temperature and flow rate, the quickest possible actuation times of the valves and the local pressure loss coefficients with a view to the maximum loads.

5.1.3.3 Missiles and Whipping Pipes

Note:

If loads on the containment vessel as a result of impacting missiles and whipping pipes have to be taken into consideration, their calculation shall be specified in each individual case.

5.2 Boundary Conditions and Assumptions

5.2.1 General

The boundary conditions, assumptions and input data for the determination of the loads shall be justified and documented.

5.2.2 Leak Sizes and Opening Characteristics

(1) The following leak sizes shall be used in the design of the containment vessel

a) Up to two times the internal pipe c cross-section (2 A) in the case of a reactor coolant pipe

b) Circumferential ruptures in the case of high-energy pipes having a diameter smaller than or equal to DN 50

c) The following leak assumptions apply to pipes having a diameter greater than DN 50 and meeting the requirements of the General. Specification on Basic Safety

   ca) Slowly opening subcritical cracks in main steam and main feedwater pipes between steam generator and the first outer isolation whose size shall be determined on the basis of fracture mechanics. Instead of such a determination, 0.1 times the internal cross-section of the pipe (0.1 A) may be postulated (static conditions).

   cb) Circumferential ruptures at highly stressed circumferential welds of high-energy pipes, if the high-energy conditions apply during more than 2% of the overall operating time and if the nominal operating stress is greater than 50 N/mm2. Deviations, e.g. because of process engineering measures, secondary protective measures or far-reaching quality assurance measures, shall be justified.

   cc) Slowly opening subcritical cracks in pipes having a nominal operating stress of less than 50 N/mm2, or if high-energy conditions apply during less than 2% of the operating time. The leak size shall be determined on the basis of fracture mechanics. instead of such a determination, 0.1 times the internal pipe diameter may be postulated (0.1 A) (static conditions). For high-energy pipes in which, due to the low nominal operating stress (less than 50 N/mm2), no supercritical circumferential rupture is assumed, it shall also be ascertained that the overall operating stress level (dead weight, internal pressure and obstructed thermal expansion) is sufficiently low (less than 3 Sm in accordance with Sec. 7.7 of KTA 3201.2, determined by means of a linear elastic calculation).

   cd) Slowly opening subcritical cracks in all high-energy pipes whose size is 0.1 times the internal cross-section of the pipe (quasi-stationary), irrespective of the justification in terms of fracture mechanics.

(d) For all components which do not meet the requirements of the General Specification on Basic Safety (or are not covered by this specification), the leak assumptions shall be specified in each individual case on the basis of the existing material quality and design features.

Notes:

1. The ‚high-energy" piping condition is deemed to have been met if the operating pressure is greater than or equal to 20 bar, or if the operating temperature is greater than or equal to 100 °C.
2. The specification of a leak size of 0.1 times the internal cross-section of a pipe is consistent with current practice on the basis of RSK Guideline 21.1 (6/84) and RSK Guideline 21.2 (6/83) and the General Specification on Basic Safety.

(2) For pipes larger than DN 250, a linear leak opening characteristic with a leak opening time of 15 ms shall be used in the case of quickly opening circumferential ruptures. Deviations from this procedure shall be justified. For all smaller pipes, opening times and opening characteristics shall be specified in each individual case.

Note:

For the determination of the loads acting on the containment vessel, the opening characteristic is only of importance with respect to the local loads.

(3) The leak sizes to be investigated for the determination of the overall, distributed and local loads shall be taken from Table 5-1; leak sizes to be specified in each individual case in accordance with Section 5.2.2.1 (d) are not contained in this table.

Note:

Table 5-1 shows the loads and types of loads to be considered and resulting from the leak sizes to be postulated in accordance with Section 5.2.2 (1). The determination may be limited to those leak sizes which determine the design. Thus, no relevant loads are anticipated in the cases of Section 5.2.2 (1) items ca) and cc).

5.2.3 Plant States

(1) Basically, the most unfavorable operating condition shall be used for the determination of the loads. However, in the case of pressurized water reactors, the nominal operating condition may be used for leaks in the reactor cooling pipe.

(2) In order to cover structural tolerances, the assumptions of

a) the calculated volume of the pressure boundary of the reactor coolant and of the secondary circuit in accordance with Section 5.2.4 (1) shall be increased by 2%,

b) the calculated free volume in the containment vessel shall be decreased by 2%, and

c) both the internal and the external surface of the containment vessel may be decreased by 2%, and the calculated surface of the internals acting as heat sinks inside and outside the containment shall be decreased by 10%.

(3) The lower operating limits of temperature and humidity shall be assumed as the state of the atmosphere in the reactor building prior to the occurrence of the incident. With respect to the temperature of the metal and concrete internals, the upper operating limits shall be used.

(4) For the determination of the maximum pressure and temperature buildup in the containment vessel, it shall be assumed that no air escapes from the containment vessel.

5.2.4 Energy Release

(1) For the determination of the maximum pressure and maximum temperature in the containment vessel in the case of a loss of coolant from the primary system, it shall be postulated that during the blowdown duration of the reactor coolant, there will also be a release of the total mass and energy of the coolant on the secondary side of a steam generator - provided there are any steam generators -including those system sections which are not isolated.

(2) In addition, the heat transfer from the steam generators to the escaping primary coolant shall be taken into consideration, unless already covered by the determination carried out in accordance with Section 5.2.4 (1).

(3) In addition, the decay heat generated during the blowdown duration shall. be added to the energy of the coolant which escaped into the containment vessel. For this purpose, the decay power after 2.5 years of operation at nominal operating conditions in accordance with DIN 25463-1 or DIN 25463-2 shall be determined using an error allowance of twice the standard deviation (2σ). It may be assumed that, after the end of the refill phase, it will be possible to prevent any long-term discharge of steam from the pressure boundary.

(4) The energy stored and released by the reactor core, the reactor pressure vessel, its internals and the remaining parts of the pressure boundary of the reactor coolant shall be added to the energy of the coolant released into the containment vessel.

(5) Within the scope of the leak assumptions in accordance with Section 5.2.2, those assumptions in terms of process and systems engineering concerning the incident course shall be used which,

a) in the case of a leak in the primary circuit, lead to the shortest possible blowdown duration with the highest possible energy release into the containment vessel,

b) in the case of a leak in the secondary circuit lead to the maximum energy release into the containment vessel, and

c) in the came of leaks in systems outside the containment vessel lead to the maximum energy release into the annulus, considering the dissipation of energy.

Note:

In the case of a leak in the secondary circuit, and depending on the initial state of the plant as well as the size and location of the leak, the maximum energy release into the containment vessel will be essentially determined by the respective process engineering and control and instrumentation concept of the plant for leak detection, leak isolation and steam generator feeding.

		Types of Loads				
		inside the containment vessel			outside the containment vessel	
		overall	distributed	local	overall	distributed
Leak sizes in accordance with Section 5.2.2 (1), enumeration	a)	X	X	-	-	-
	b)	X	X	X	X	X
	ca)	X	X	-	- 1)	- 1)
	cb)	X	X	X	X	X
	cc)	X	X		X	X
	cd)	-	-	X	-	-

1) Note: Loads on the containment vessel are prevented by structural measures

Table 5-1: Allocation of types of loads to leak sizes

5.3 Validations and Demonstrations

(1) As a matter of principle, preliminary calculations and confirmatory verifications of experiments shall be used to demonstrate that the models used and the associated computer codes are capable of describing physical processes with view to the loads to be determined in terms of size and functional sequence.

(2) If, in individual cases, such a validation cannot be obtained, the assumptions for the influencing parameters and models shall be made in such a way that their possible contributions to the loads to be determined are covered in their entirety.

(3) For the following parameters, the actual values shall be demonstrated after completion of construction:

a) free volume of the containment vessel,

b) free volume of the pressure boundary of the reactor coolant,

c) free volume of the secondary side of the steam generators up to the first isolation.

(4) in addition, the surface and the thickness of the heat-absorbing structures and the thickness of the paints shall be verified for compliance with the values of these parameters on which the safety-related demonstrations were based.

(5) The results of the verifications shall be documented and compared with the values on which the safety-related demonstrations were based.

(6) In the case of deviations of the actual construction values from the values on which the calculations were based, the admissibility of the deviations shall be verified if they would lead to greater loads than those calculated.

6 Load Statements

6.1 Overall Loads

(1) The respective maximum value shall be taken from the pressure and temperature course in the containment vessel as calculated in accordance with Section 5.1.1.1. If the thermal imbalance is not covered by the model, this pressure shall be increased by 0.3 bar. The excess pressure thus determined shall be increased by 15% in order to cover calculatory uncertainties and unfavorable operating conditions. Pressure deviations resulting from structural tolerances in accordance with Section 5.2.3 (2) and deviations therefrom, if any, shall not be compensated for by this addition.

(2) If the pressure value thus obtained exceeds I bar, the increase by 0.3 bar for the thermal imbalance not covered shall be determined anew.

(3) The result of these determinations shall be used as design pressure, together with the maximum value of the temperature course in the atmosphere of the containment vessel as design temperature, for the DF1 load cane in accordance with Table 4-1 of KTA 3401.2.

(4) For the calculation of the pressure for the ST 1 load case in accordance with Table 4-1 of KTA 3401.2, this determination process shall be repeated. In this context, however, the increase by 15% may be waived.

Note:

Since the ST 1 load case, like an operating case, is classified in service limit level I and is thus subject to a similarly high stress limitation, an addition to cover calculatory uncertainties and unfavorable operating conditions need not be used separately. in all other respects, a sufficient maintenance of the functionality of the containment vessel, even if the design pressure is postulated, is also demonstrated in accordance with the protection afforded by the ST 4 load case.

(5) However, as stated in Section 6.1 (1) and (2), this determination process shall basically be repeated with an addition of 10% with respect to the break of a pipe not containing any activity, based on the most unfavorable operating condition, in order to cover calculatory uncertainties. This addition may be waived if, in the determination of the loads, the individual influencing factors have been specified in such a way that the calculatory uncertainties have already been covered. The resulting pressure shall be used, together with the maximum value of the temperature course in the atmosphere of the containment vessel, for the ST 4 load case in accordance with Table 4-1 of KTA 3401.2.

(6) For the specification of the maximum load resulting from pressure differences between the atmosphere of the annulus and the atmosphere of the containment vessel, the following values shall be quoted:

a) Maximum value of the pressure in the annulus in accordance with Section 5.1.1.2, considering the thermal imbalance and at the same time stating the time history of the temperature in the atmosphere of the annulus for the ST 5 load case in accordance with Table 4-1 of KTA 3401.2. The temperature to be used is that of the atmosphere of those areas of the containment vessel which are predominantly subjected to escaping fluids.

b) The depressurization in the containment vessel in accordance with Section 5.1.1.2 for the DF 2 load case in accordance with Table 4-1 of KTA 3401.2.

c) The possible maximum pressure resulting from malfunctions of the ventilation systems in accordance with Section 5.1.1.2 for the ST 2 load case in accordance with Table 4-1 of KTA 3401.2.

Basically, a 10% addition shall be used for these values in order to cover calculatory uncertainties. This addition may be waived if, in the determination of the loads, the influencing factors have been specified in such a way that the calculatory uncertainties have already been covered.

(7) The specification of the load statements for the DF 2 load case in accordance with Table 4-1 of KTA 3401.2 shall be made on the basis of the pressures determined in Section 6.1 (6) items a), b) or c).

6.2 Distributed Loads

(1) If thermal stresses have to be specified for the ST 1 load case in accordance with Table 4-1 of KTA 3401.2, the local and temporal course of the temperature in the wall of the containment vessel shall be used as determined in accordance with Section 5.1.2 (2).

(2) For the ST 1, ST 4, and ST 5 load cases in accordance with Table 4-1 of KTA 3401.2, the following values shall be used which have been determined in accordance with Section 5.1.2.:

a) pressure differences - increased by 15% and by at least 10 000 Pa, according to SiAnf, Annex 5, Appendix 2, and

b) temperature distribution in the wall of the containment vessel.

6.3 Local Loads

For the ST 1, ST 4, and ST 5 load cases in accordance with Table 4-1 of KTA 3401.2, the jet and reaction forces determined in accordance with Sections 5.1.3.1 and 5.1.3.2, increased by 15% according to SiAnf, Annex 5, Appendix 3, shall be used.

6.4 Load Combinations

For the consideration of stress combinations in accordance with KTA 3401.2, the loads shall be used in their time histories or an combinations of their maximum values. For the case of a consequential failure of components or systems, their simultaneous effects shall be combined.

Appendix A

Heat Transfer

The following relations shall be used for the heat transfer from the atmosphere in the containment vessel to the internal (structures) in the containment vessel:

a) Heat transfer at steel surfaces

aa) for times: $0 \le t \le t_p$

$$\alpha_s = \alpha_{max} \cdot \left(\frac{t}{t_p} \right)^{0,5} \qquad \text{(A-1)}$$

where

α_s	heat transfer coefficient between steel and air/steam mixture in W/m2K
t	time in s from the onset of the incident
t_p	time in s from the onset of the incident until reaching the pressure maximum in the containment vessel
α_{max}	$48.63 \left(\frac{E}{t \cdot V} \right)^{0.6}$ in $\frac{W}{m^2K}$
E	energy content of the primary coolant (excluding stored energy, secondary energy, etc.) in kJ
V	free containment vessel volume in m3

ab) for times: $t > t_p$:

$$\alpha_s = \alpha_{stag} + \left(\alpha_{max} - \alpha_{stag} \right) \cdot e^{-0.05 \left(t - t_p \right)} \qquad \text{(A-2)}$$

where

α_{stag}	$= 11.365 + 284.12 \bullet x$
x	ratio between steam mass and air mass in the containment vessel
α_{stag}	heat transfer coefficient for stagnant air/steam mixtures in W/m^2K

b) Heat transfer at concrete surfaces

ba) for times: $0 \le t \le t_p$

$$\alpha_m = 0.4 \bullet \alpha_p \qquad \text{(A-3)}$$

bb) for times: $t > t_p$

$$\alpha_s = \alpha_{stag} + \left(0.4 \alpha_{max} - \alpha_{stag} \right) \cdot e^{-0.05 \left(t - t_p \right)} \qquad \text{(A-4)}$$

Note:

Further details concerning the relations quoted in paras. a) and b) above are contained in Appendix D, Ref. [1], [2] and [3].

Appendix B

Subdivision of Structures

For the determination of the transient heat flux in structures of the containment vessel, the structures shall be subdivided according to the following procedure:

a) The thickness of the layer which is directly on the surface of a structure is calculated as follows:

$$l \le Bi \cdot \frac{\lambda}{\alpha_{max}} \qquad \text{(B-1)}$$

l	=	thickness of the surface layer
λ	=	thermal conductivity in W/mK
α_{max}	=	maximum heat transfer coefficient in accordance with Appendix A, item a
Bi	=	0.2 = Biot number

b) The layers located farther to the inside of the structure can be enlarged step by step in accordance with the following quotients

$$0.5 \le r = \frac{l_i + 1}{l_i} \le 2 \qquad \text{(B-2)}$$

c) In the case of structures which absorb or release different amounts of heat from or to the two sides, the subdivision process shall be applied on both sides straight through to the rear boundary, and the respective smaller layer thickness shall be selected. Residual layers shall be combined with adjacent layers in such a way that the quotient r is adhered to.

d) If a structure is made up of several plies of different materials, the boundary layers at the boundary between two materials shall be selected in such a way that their heat transmission resistances are the same. Each ply shall be subdivided into at least 2 layers.

e) In this subdivision of layers, time interval t should be selected as follows:

$$t = A \cdot \frac{\lambda \cdot \rho \cdot c_p}{\alpha_{max}^2} \quad \text{in s} \qquad \text{(B-3)}$$

where $0.01 \le A \le 0.2$

ρ	density of the structural material in kg/m3
c_p	specific heat capacity in J/kg K

Note:

Further details concerning the relations quoted in paras. a), b) and e) above are contained in Appendix D, Ref. [1], [2] and [3].

Appendix C

Regulations Referred to in this Safety Standard

(Regulations referred to in this 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 nuclear energy and the protection against its hazards (Atomic Energy Act – AtG) of December 23, 1959, in the new version promulgated on July 15, 1985 (BGBl. I 1985, p. 1565), last revised by Article 2 of the Law of July 20, 2017 (BGBl. I p. 2802)
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 according to Article 10 by Article 6 of the Act of January 27, 2017 (BGBl. I, p. 114, 1222)
SiAnf	(2015-03)	Safety Requirements for Nuclear Power Plants (SiAnf) of 22 November 2012 (BAnz AT 24.01.2013 B3), revised version of 3 March 2015 (BAnz AT 30.03.2015 B2).
Interpretations to SiAnf	(2015-03)	Interpretations of the "Safety Requirements for Nuclear Power Plants of 22 November 2012" (BAnz AT 24.01.2013 B3), revised version of 3 March 2015 (BAnz AT 30.03.2015 B2)
General Specification "Basic Safety"	(1979-01)	RSK Guidelines for Pressurized Water Reactors, 2nd Edition, January 24, 1979, Appendixes to Chapter 4.2 1. List of Systems and Components 2. General Specification 'Basic Safety'
KTA 3201.2	(2013-11)	Components of the Primary Circuit of Light Water Reactors; Part 2: Design, Construction and Calculation
KTA 3401.2	(2016-11)	Reactor Containment Vessels of Steel; Part 2: Design, Construction and Calculation
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

Appendix D

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