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Safety Standards

of the
Nuclear Safety Standards Commission (KTA)

KTA 3203 (6/01)

Surveillance of the Irradiation Behaviour of Reactor Pressure Vessel Materials of LWR Facilities

(Überwachung des Bestrahlungsverhaltens von Werkstoffen der Reaktordruckbehälter von Leichtwasserreaktoren)

A previous version of this Safety Standard was issued 3/84

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KTA SAFETY STANDARD

June 2001	Surveillance of the Irradiation Behaviour of Reactor Pressure Vessel Materials of LWR Facilities	KTA 3203

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PLEASE NOTE: Only the original German version of this safety standard represents the joint resolution of the 50-member Nuclear Safety Standards Commission (Kerntechnischer Ausschuss, KTA). The German version was made public in Bundesanzeiger No. 235 b on December 15, 2001. Copies may be ordered through the Carl Heymanns Verlag KG, Luxemburger Str. 449, 50939 Koeln (Telefax +49-221-94373-603).

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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, the 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.

Fundamentals

(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 the damage arising from the construction and operation of the facility (Sec. 7 para 2 subpara 3 Atomic Energy Act) in order to attain the protection goals specified in the Atomic Energy Act and the Radiological Protection Ordinance (StrlSchV) and which are further detailed in the ”Safety Criteria for Nuclear Power Plants” and in the ”Guidelines for the Assessment of the Design of PWR Nuclear Power Plants against Incidents pursuant to Sec. 28 para 3 of the Radiological Protection Ordinance (StrlSchV) - Incident Guidelines”.

(2) In the Safety Criteria, Criterion 1.1 ("Principles of safety precautions") requires, among other things, extensive quality assurance in manufacturing, erection and operation, while Criterion 2.1 ("Quality guarantee") requires, among other matters, the application, establishment and observance of design, material, construction, inspection and operating specifications as well as documentation of quality monitoring. Criterion 4.1 ("Reactor-coolant pressure boundary") requires, among other things, that dangerous leakage, rapidly propagating cracks and brittle fracture have to be excluded in accordance with the state of science and technology. KTA safety standard 3203 defines provisions to be made to meet these requirements within their scope of application. For primary circuit components the requirements of the aforementioned criteria are defined to comprise the following KTA safety standards.

KTA 3201.1	Materials and Product Forms,
KTA 3201.2	Design and Analysis,
KTA 3201.3	Manufacture,
KTA 3201.4	Inservice Inspections and Operational Monitoring.

(3) In particular, KTA safety standard 3203 defines requirements to be met regarding the monitoring of reactor pressure vessel (RPV) materials behaviour under the effects of neutron irradiation, especially with respect to the:

a) performance and evaluation of irradiation surveillance programs,

b) determination of neutron fluence,

c) determination of the irradiation temperature,

d) retention of specimens,

e) documentation.

(4) The irradiation surveillance program especially serves to determine, by means of accelerated irradiation specimen capsules, the strength and toughness properties of base and weld materials in the core beltline region of the RPV as a function of defined neutron irradiation.

1 Scope

This safety standard shall apply to the monitoring of irradiation behaviour of beltline materials in the RPV pressure-retaining walls of light-water reactors.

2 Definitions

(1) Lead factor

The lead factor is the ratio of the neutron fluences (for neutron energies E > 1 MeV) of the irradiated specimens in the capsule to the maximum irradiated region of the ferritic internal RPV wall subject to the same irradiation time.

(2) Limit value of the reference temperature (RT_{limit})

The limit value of the reference temperature (RT_{limit}) is the highest adjusted reference temperature on which the proof of equivalent safety margin against brittle fracture is based.

(3) Beltline region

The beltline region is that wall area of the RPV subjected to irradiation which directly surrounds the active part of the reactor core (effective height of that part of the fuel rods filled with fuel), as well as adjacent regions which, as a result of the precalculated increase in reference temperature, have to be considered in the selection of the materials to be monitored.

(4) Assessment fluence (AF)

The assessment fluence is the neutron fluence used in the assessment against brittle fracture and for which the result of the assessment is valid.

(5) NDT temperature

The NDT (Nil Ductility Transition) temperature is the highest temperature at which a test specimen will fail in drop-weight testing.

(6) Neutron fluence (Φ)

The neutron fluence is the neutron flux density integrated over the irradiation time.

(7) Neutron flux density (φ)

The neutron flux density is the quotient of the number of neutrons of a defined energy level which in a certain time interval enter a small sphere around the spatial point considered, and of the product of the cross-sectional area of this sphere and the time interval. The neutron flux density is identical to the product of the neutron number density and the average velocity of the neutrons.

(8) Neutron spectrum

The neutron spectrum is the distribution of the neutron flux density as a function of the neutron energy. In general, the neutron spectrum is presented as groups assigned to specific energy intervals.

(9) Reference temperature (RT_{NDT})

The reference temperature is established as follows:

a) Determine a temperature T_{NDT} that is at or above the nil-ductility transition temperature by drop-weight tests.

b) At a temperature not greater than T_{NDT} + 33 K each specimen of the notched-bar impact test (Charpy-V-notch specimen) shall normally exhibit at least 0.9 mm lateral expansion and not less than 68 J absorbed energy. When these requirements are met, T_{NDT} is the reference temperature RT_{NDT}.

c) In the event that the requirements of (b) above are not met, conduct additional notched-bar impact tests (Charpy-V-notch specimen) in groups of three specimens to determine the temperature T_{KV} at which they are met. In this case the reference temperature $RT_{NDT} = T_{KV}$ - 33 K. Thus, the reference temperature RT_{NDT} is the higher of T_{NDT} and T_{KV} - 33 K.

d) When a notched-bar impact test has not been performed at T_{NDT} + 33 K, or when the notched-bar impact test does not exhibit a minimum of 68 J and 0.9 mm lateral expansion, a temperature representing a minimum of 68 J and 0.9 mm lateral expansion shall normally be obtained from the impact-energy versus temperature curve developed from the minimum values obtained from all specimens.

(10) Adjusted reference temperature ($RT_{NDT\,j}$)

This means the reference temperature as adjusted for irradiation effects by adding to the reference temperature the transition temperature shift ΔT_{41} to obtain: $RT_{NDT\,j} = RT_{NDT} + \Delta T_{41}$.

(11) Authorized inspectors

Authorized inspectors are persons nominated or consulted by the licensing or supervisory authorities. Unless specified otherwise by individual requirements, the authorized inspector is the inspector in accordance with Sec. 20 of the Atomic Energy Act.

(12) Transition-temperature shift (ΔT_{41})

The transition-temperature shift is the difference in the index temperatures for the best-fit (average) Charpy curve measured before and after irradiation of specimens at an absorbed energy of 41 J.

3 General Principles

3.1 Purpose of the irradiation surveillance program

Specimens of the original ferritic materials shall be subject to accelerated irradiation in capsules inside the reactor pressure vessel to experimentally verify the tensile and fracture toughness properties of the RPV material at assessment fluence. The location of the upper-shelf curve shall be determined either

a) indirectly according to the RT_{NDT} concept by comparing test results obtained from accelerated-irradiation specimens and unirradiated specimens,

or

b) to the fracture toughness concept by examining irradiated fracture toughness specimens (e.g. by determination of the reference temperature T_0 to ASTM E 1921-97).

3.2 Necessity of implementing an irradiation surveillance program

(1) At a neutron fluence of less than $1 \bullet 10^{17}$ cm^{-2} (for neutron energies E > 1 MeV) in the maximum irradiated region of the ferritic inner wall of the RPV, no influence of radiation on the tensile and fracture toughness properties shall be considered in the proof of safety against brittle fracture. For this reason, no irradiation surveillance program is required.

(2) At a neutron fluence equal to or greater than $1 \bullet 10^{17}$ cm^{-2} and equal to or smaller than $1 \bullet 10^{19}$ cm^{-2} (for neutron energies E > 1 MeV) in the maximum irradiated region of the ferritic inner wall of the RPV, the proof of safety against brittle fracture to KTA 3201.2, section 7.9 shall be based on the limit value of the reference temperature RT_{limit} = 40 °C as per **Figure 3-1**. This limit value RT_{limit} shall be verified to cover RT_{NDTj} as a result of an irradiation program in accordance with **Table 3-1**. The adjusted reference temperature RT_{NDTj} thus determined shall be taken for the proof of safety against brittle fracture.

(3) At a neutron fluence greater than $1 \bullet 10^{19}$ cm^{-2} (for neutron energies E > 1 MeV) in the maximum irradiated region of the ferritic inner wall of the RPV, the proof of safety against brittle fracture to KTA 3201.2, section 7.9 shall be based on the limit value of the reference temperature RT_{limit} as per **Figure 3-1**. This limit value RT_{limit} shall be verified to cover RT_{NDTj} as a result of an irradiation program in accordance with **Table 3-2**. The adjusted reference temperature RT_{NDTj} thus determined shall be taken for the proof of safety against brittle fracture.

(4) For materials for which no irradiation program is provided and the radiation behaviour of which is not covered by other materials, the RT_{limit} as per **Figure 3-1** shall be used.

No. of specimen set	Charpy-V-notch specimens		Tensile specimens		Time of withdrawal
	BM	WM	BM	WM	
1	12	12	3	3	unirradiated
2	12	12	3	3	≈ 50 % AF
3	12	12	3	3	≥100 % AF

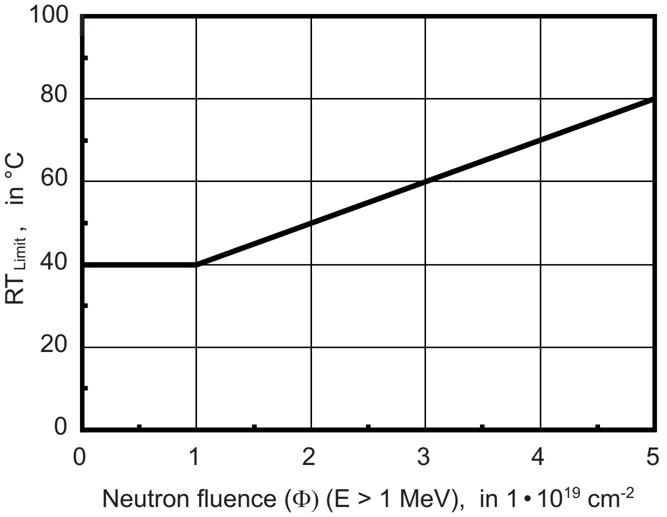
BM : base metal
WM : weld metal
AF : assessment fluence

Table 3-1: Number of test specimens for each irradiation exposure set for assessment fluences equal to or smaller than $1 \bullet 10^{19}$ cm^{-2} at neutron energies E > 1 MeV

No. of specimen set	Charpy-V-notch specimens			Tensile specimens			Time of withdrawal
	BM I	BM II	WM	BM I	BM II	WM	
1	12	12	12	3	3	3	unirradiated
2	12	12	12	3	3	3	≈ 50 % AF
3	12	12	12	3	3	3	≥100 % AF

BM : base metal
WM : weld metal
AF : assessment fluence

Table 3-2: Number of test specimens per irradiation exposure set for assessment fluences greater than $1 \bullet 10^{19}$ cm^{-2} at neutron energies E > 1 MeV



This limit value applies to neutron fluences (at neutron energies E > 1 MeV) equal to or greater than $1 \bullet 10^{17}$ cm^{-2} and for materials meeting the requirements of section B 5.1. At present, results are available for boiling water reactors amounting to neutron fluences (at neutron energies E > 1 MeV) of up to $1 \bullet 10^{18}$ cm^{-2}

Figure 3-1: Limit value of the reference temperature RT_{limit} for base and weld metals as a function of the neutron fluence (RT_{limit} curve)

4 Irradiation surveillance program

4.1 Irradiation plan

(1) An irradiation plan shall be established for implementing the irradiation surveillance program, which shall contain the following data:

a) description of the materials in the beltline region (chemical composition, heat treatments, results of acceptance tests) and which materials have to be included in the irradiation program,
b) materials testing and specimen-taking plan,
c) intended position of the encapsuled specimen sets in the RPV,
d) calculated fluence for the ferritic inner wall of the RPV (maximum value as well as axial and azimuthal distribution) and its distribution over the wall thickness,
e) lead factor of the irradiation specimens,
f) number and type of neutron detectors and temperature monitors,
g) location of individual specimens, neutron detectors and temperature monitors,
h) fabrication documentation of the production control test piece or weld test coupon,
i) data on capsules (materials, fabrication, testing),
k) presence of the authorized inspector.

(2) The irradiation plan shall be submitted to the authorized inspector prior to fabricating the specimens.

4.2 Requirements for capsules containing irradiation exposure specimens

(1) The material test specimens, neutron detectors and temperature monitors shall be located in capsules made of corrosion-resistant material.

(2) The capsules including the filling material shall be designed to ensure that sufficient heat transfer from the inserted specimens through the wall to the coolant is achieved. This may, e.g. be achieved by surface area contact between specimens, filling material and capsule.

(3) The differences in neutron flux density in one series of specimens shall be kept as low as possible by adequate positioning of the specimens.

(4) The capsules shall be designed to be leak-tight over the intended period of utilization. The leak-tightness shall be proven to the authorized inspector prior to installing the capsules in the RPV.

4.3 Location of capsules in the RPV

(1) The capsules shall normally be located in the RPV such that lead factors of 1.5 to 12 are obtained.

(2) The means for attaching and positioning the capsules within the RPV shall be designed and located such that the capsules can be inserted and withdrawn easily and reliably, and damage during operation can be excluded.

4.4 Number of specimen sets

The basic program shall cover at least two sets of specimens to establish the irradiated specimen properties and one specimen to establish the unirradiated specimen properties.

4.5 Point in time of insertion and withdrawal of specimen sets

(1) The specimen sets shall be inserted at the earliest upon completion of hot trial operation.

(2) The point in time of withdrawal of irradiated specimen sets shall be selected such that the neutron fluence with two specimen sets used is approximately 50 % and at least 100 % of the assessment fluence of the RPV.

(3) The specimen sets may be withdrawn during planned shutdowns, e.g. during refuelling.

5 Selection of materials for irradiation specimens

5.1 Selection criteria

The irradiation specimens shall be taken from original materials and, with respect to the manufacturing process, shall correspond to those materials which are used in the RPV beltline region.

5.2 Test coupon

(1) For the irradiation surveillance program a test coupon shall be welded in the presence of the authorized inspector under the same conditions as the original RPV beltline weld to be monitored.

(2) An adequately dimensioned test coupon of the production control test (production control test piece) may be taken to remove specimens for the irradiation surveillance program, if the production control test weld has been welded to clause 12.2.2.2 of KTA 3201.3 under the same conditions as the original beltline weld.

(3) Where a particular weld test coupon is required for the irradiation surveillance program, those base materials, weld filler metals and consumables shall be used which have been used for welding the RPV beltline weld to be monitored. For such a test coupon parts shall be used which have been cut off from original forgings or plates in the quenched and tempered condition. The welding procedure as well as the welding variables shall also meet the conditions specified for welding the beltline weld to be monitored.

(4) The heat treatments of the test coupon shall correspond to those of the RPV beltline weld to be monitored. They shall be normally carried out as travelling or simulated heat treatments.

(5) The test coupons to be taken from the production control test piece or weld test material used to fabricate irradiation exposure specimens shall represent, in dependence of the assessment fluence, either one base metal and the weld metal (see **Table 3-1**) or the two adjacent base metals and the weld metal (see **Table 3-2**). The required base metal specimens may also be taken from material coupons of the same heat.

5.3 Material specimens and reserve material

A sufficient amount of material shall be retained for specimen-taking so that besides the sets of specimens to be selected according to 4.4 which are required to establish the mechanical properties prior to and after irradiation, sufficient material of at least 1.5 m weld seam length is available for taking further specimen sets or for supplementary tests.

Note:
In general, a test coupon with a welded seam length of approx. 2 m will suffice for the irradiation surveillance program including reserve material.

5.4 Specimen orientation and location

5.4.1 General

The specimens for the unirradiated set of specimens and the set of specimens to be irradiated shall be taken as near as possible to each other and their location shall be documented in the irradiation plan.

5.4.2 Base material

(1) The test specimens of the base metal shall be taken as transverse (axial) specimens with a longitudinal axis either transverse to the main direction of forming or parallel to the rotational axis of symmetry. For impact or fracture toughness specimens the notch axis shall be perpendicular to the plane of transverse and longitudinal directions or perpendicular to the cylindrical surface.

(2) The locations of specimen-taking in seamless cylindrical rings which are remote from discontinuities and are to be used for shell courses, shall be at a depth of at least one quarter of the quenched and tempered wall thickness, but not more than 80 mm below the cylinder inner surface and be at a distance of at least half the quenched and tempered wall thickness, but not more than 160 mm away from the end surface of the edges dressed for heat treatment. The specimen-taking locations in plates shall be at a depth of at least one quarter of the quenched and tempered wall thickness below the rolling surface and be at a distance of at least half the quenched and tempered wall thickness from the end surface of the edges dressed for heat treatment.

5.4.3 Weld metal

Specimens from the weld metal shall be taken as follows::

a) Impact or fracture toughness test specimens shall be taken as transverse specimens with the notch axis perpendicular to the direction of welding and weld surface.
b) Tensile specimens representing weld metal shall be taken in parallel to the direction of welding.
c) Edge beads, cover layers and the area between root and filler layers shall not be used for test specimens.
d) The other areas of the weld seam volume may be considered equivalent.

6 Testing and evaluation

6.1 General

(1) The tests and evaluations shall normally be made by certified test laboratories.

(2) The tests on irradiated specimens shall normally be conducted within one year after their withdrawal.

(3) Special evaluations for considering the neutron flux density are not required for RPV materials meeting the requirements of section B 5.1.

6.2 Irradiation temperature

6.2.1 Determination of the irradiation temperature

(1) The irradiation temperature on which the evaluation is based shall be determined from the coolant temperature and the temperature increase resulting from gamma radiation.

(2) By means of suitable experimental and analytical methods the temperature increase in the specimens resulting from adsorption of gamma radiation shall be determined with respect to the coolant temperature.

(3) The irradiation temperature shall normally not exceed the temperature of the ferritic RPV inner wall by more than 5 K.

Note:
Coolant temperature in the case of pressurized water reactors is the coolant inlet temperature and in the case of boiling water reactors the temperature in the backflow section of the core area.

6.2.2 Temperature monitors

(1) Temperature monitors shall be inserted in the specimen capsules to determine an upper temperature limit. The temperature monitors listed in **Table 6-1** may, e.g. be used.

(2) The temperature monitors to be used shall be selected such that the highest temperature of the irradiation specimens can be determined over the entire exposure time in consideration of the temperature increase due to gamma radiation and operational temperature changes with a measurement uncertainty of 10 K.

6.2.3 Location of temperature monitors

Temperature monitors shall normally be placed at locations comparable to those selected for neutron detectors.

Temperature monitor	Melting temperature, in °C
Pb Ag 1.7 Sb 6	263
Bi	271
Pb Ag 1.9 Sb 5	272
Pb Ag 1.9 Sb 4.5	273
Pb Ag 1.9 Sb 4.3	278
Pb Ag 2 Sb 4	280
Pb Ag 2 Sb 3.5	284
Pb Ag 2 Sb 3	288
Pb Pt 5	290
Pb Ag 2 Sb 2	293
Pb Ag 2.5	304
Pb Ag 1.75 Sn 0.75	308
Pb In 5	314
Pb Zn 0.5	318
Pb	327

The melting temperature corresponds to the temperature where significant deformation occurs on the specimen. It shall be determined batch by batch.

As experience has shown, melting-type monitors are capable of measuring temperatures with an uncertainty of approx. 5 K.

Table 6-1: Temperature monitors

6.3 Neutron fluence determination

6.3.1 Principles

(1) Neutron field characteristics shall be fixed for determining the neutron fluences in the test specimens during irradiation and for calculating the lead factor.

(2) For each reactor, the complete neutron spectrum shall be calculated once for the specimen location and the RPV inner wall at the location of maximum flux density. The calculation shall be based on an analytical program according to the neutron transport theory.

(3) When evaluating irradiation surveillance programs, the following characteristics shall be determined in due consideration of the irradiation history:

a) the spectral distribution of the neutron flux density for the energy range of the test specimens which is required for evaluating the detector results,

b) the neutron fluence for neutron energies $E > 1$ MeV of the irradiated specimens,

c) the peak neutron fluence for $E > 1$ MeV at the RPV ferritic inner wall,

d) the lead factor.

(4) The calculation of the neutron fluence shall be compared with the evaluation of the detector results.

(5) The detectors shall be evaluated to DIN 25 456-1.

6.3.2 Selection of neutron detectors

(1) A method applied to representative reactors and proved to be reliable shall be used which covers the calculation of neutron spectra and the selection, location and evaluation of the neutron detectors.

(2) Where the proven method is altered, then the reliability of the new method shall be verified by applying it in parallel and together with the already proven method in at least one representative reactor.

(3) Within each set of irradiation specimens, 3 similar detectors for neutron fluence determination shall be inserted at respective locations, irradiated and evaluated.

(4) The neutron detectors shown in **Table 6-2** should be used.

Neutron detector	Nuclear reaction to be evaluated
Iron to DIN 25 456-2	$^{54}Fe(n,p)^{54}Mn$
Niobium to DIN 25 456-4	$^{93}Nb(n,n')^{93}Nb^{m}$
Cobalt 1)	$^{59}Co(n,\gamma)^{60}Co$

1) The cobalt detector is used for the determination of the thermal neutron fluence which can be used, where required, for correcting the fast neutron fluences determined by other neutron detectors.

Table 6-2: Neutron detectors

6.4 Mechanical tests

6.4.1 Extent of testing

(1) In addition to the tests performed as per KTA 3201.1 and KTA 3201.3 the following specimens shall be provided to determine the characteristic values indicated:

a) Tensile test specimens for unirradiated and irradiated sets of specimens for determining the yield strength R_{eH} or proof stress $R_{p0.2}$, tensile strength R_m, elongation at fracture A_5 as well as percentage elongation before reduction A_g and reduction of area Z at room temperature and at 150 °C as well as at the temperature corresponding to the long-term irradiation temperature of the specimens. This temperature shall not be exceeded because of the annealing effect.

b) Impact test specimens (Charpy-V-Specimens) for unirradiated and irradiated sets of specimens for determining the complete absorbed energy-versus-temperature curves including lateral expansion and ductile fracture percentage, with the curves beginning at the lower shelf, characterized by a ductile percentage < 5% of the fracture area, up to the temperature corresponding to the long-term irradiation temperature of the specimens.

6.4.2 Performance of tests and examinations

(1) Compact and composite specimens may be used to perform the test and examinations.

(2) The tensile test shall be performed to DIN EN 10 002-1 and DIN EN 10 002-5 with a specimen shape to DIN 50 125 using a short proportional test bar ($L_0 = 5 \cdot d_0$). The bar head shape may deviate from that prescribed in this standard. Load displacement diagrams shall be recorded.

(3) The instrumented notched bar impact test shall be performed to DIN EN 10 045-1 on Charpy-V-notch specimens; load-time or load-path plots shall be recorded and evaluated.

(4) Where the toughness properties are checked by examining irradiated fracture toughness test specimens, the fracture toughness tests may be performed, e.g. to ASTM E 1921-97.

6.4.3 Determination and evaluation of material characteristics

(1) The following material properties shall be determined:

a) the yield strength R_{eH} or proof stress $R_{p0.2}$, tensile strength R_m, elongation at fracture A_5 as well as percentage elongation before reduction A_g and reduction of area Z at room temperature and at 150 °C as well as at the temperature corresponding to the long-term irradiation temperature of the specimens,

b) the transition temperature shift from average (best-fit) curves at an absorbed energy of 41 J (ΔT_{41}),

c) the adjusted reference temperature ($RT_{NDT\,j}$) from $RT_{NDT} + \Delta T_{41}$.

(2) The adjusted reference temperature $RT_{NDT\,j}$ thus determined shall be compared to the RT_{limit} value of the respective reactor. Where values are available from two irradiated specimen sets, interpolation or extrapolation may be applied to obtain the assessment fluence. For interpolation and extrapolation each suitable function is permitted, but the exponential function $RT_{NDT\,j} = A \cdot \Phi^n$ shall preferably be used. Where values are available from only one irradiated specimen set, extrapolation is not permitted.

(3) Where the determination of the average best-fit curves to obtain transition temperature shifts is always made to the same evaluation method, no safety margin is required for the determination of $RT_{NDT\,j}$.

(4) It shall be verified that:

a) $RT_{NDT\,j} \leq RT_{limit}$

b) the upper-shelf energy characterized by a ductile percentage > 95% of the fracture area does not exceed a value of absorbed energy of 68 J (individual value).

(5) Where with an increase in neutron fluence lower values for $RT_{NDT\,j}$ are obtained, the highest value determined for $RT_{NDT\,j}$ shall be used to verify that $RT_{NDT\,j} \leq RT_{limit}$.

(6) Where the determined reference temperature $RT_{NDT\,j}$ exceeds RT_{limit}, the safety of the reactor pressure vessel shall be verified by other means, if required.

(7) Where the upper-shelf energy is less than 68 J, the safety of the reactor pressure vessel shall be verified by other means, if required.

7 Retention of specimens

All tested and untested specimens as well as the reserve material shall be retained.

8 Documentation

(1) The documentation shall permit complete traceability of the specimen history from fabrication to specimen evaluation and testing upon irradiation.

(2) The test results obtained prior to and upon irradiation shall be documented.

(3) The documents required for the fabrication of the weld test coupon or production control test piece (see section 5.2), such as test and inspection sequence plan, welding procedure sheet, heat treatment plan as well as materials testing and specimen-taking plan shall be incorporated in the documentation. In addition, the documentation shall cover the design-reviewed irradiation plan as well as all tests performed together with their results.

(4) The records to be documented shall be clearly arranged. A table of contents shall precede the documents.

Annex A

Regulations referred to in this Safety Standard

(The references exclusively refer to the version given in this Annex. Quotations of regulations referred to therein refer to the version available when the individual reference below was established or issued.)

AtG		Act on the Peaceful Utilization of Atomic Energy and the protection against its hazards (Atomic Energy Act) of December 23, 1959 (BGBl. I, p. 814) as Amended and Promulgated on July 15, 1985 (BGBl. I, p. 1565), last Amendment by the Act of March 5, 2001 (BGBl. I, p. 326)
KTA 3201.1	(06/98)	Components of the Reactor Coolant Pressure Boundary of Light Water Reactors; Part 1: Materials and Product Forms
KTA 3201.2	(06/96)	Components of the Reactor Coolant Pressure Boundary of Light Water Reactors; Part 2: Design and Analysis
KTA 3201.3	(06/98)	Components of the Reactor Coolant Pressure Boundary of Light Water Reactors; Part 3: Manufacturing
KTA 3201.4	(06/99)	Components of the Reactor Coolant Pressure Boundary of Light Water Reactors; Part 4: Inservice Inspection and Operational Monitoring
DIN EN 10 002-1	(04/91)	Tensile testing of metallic materials; Part 1: Method of test at ambient temperature; including amendment AC 1: 1990; German version EN 10002-1:1990 and AC1:1990
DIN EN 10 002-5	(02/92)	Tensile testing of metallic materials; Part 5: Method of test at elevated temperatures; German version EN 10002-5:1991
DIN EN 10 045-1	(04/91)	Charpy impact test on metallic materials; Part 1: Test method; German version EN 10045-1:1990
DIN 25 456-1	(10/99)	Neutron fluence measurements; Part 1: Fluence determination of fast neutrons with activation and fission detectors
DIN 25 456-2	(10/99)	Neutron fluence measurements; Part 2: Fluence determination of fast neutrons with iron-activation detectors
DIN 25 456-4	(10/99)	Neutron fluence measurements; Part 4: Fluence determination of fast neutrons with niobium-activation detectors
DIN 50 125	(04/91)	Test pieces for the tensile testing of metallic materials
SEP 1325	(12/82)	Drop-weight test to W.S. Pellini
ASTM E 1921-97		Standard Test Method for Determination of Reference Temperature, T_0, for Ferritic Steels in the Transition Range

Annex B

Data for the determination and criteria for use of the RT_{limit} curve

B 1 General

(1) The design curves of KTA 3203 (3/84) [1] were established on the basis of irradiation results obtained in the sixties and early seventies, which in majority originated from the U.S.A. In the years that followed the fabrication techniques for base materials and weld metals made essential progress so that the old irradiation results for today`s and future nuclear power stations are no more absolutely representative. In the period following the introduction of KTA Safety Standard 3203 the evaluation of the results obtained from irradiation surveillance programs showed that the design curves established at that time in some cases overestimated and in some cases underestimated the reaction of materials to radiation.[2], [3].

(2) This annex contains criteria for evaluating the results of irradiation surveillance programs and predicting the irradiation behaviour of future reactor pressure vessels.

B 2 Basic principles for evaluating results

(1) All German nuclear power stations are subject to an irradiation surveillance program to cover base materials and weld metals of the RPV beltline region. For most of the nuclear power stations the results of the unirradiated and the first irradiated set of specimens and for many of them also those of the second irradiated set of specimens are available. The results of irradiation surveillance programs of German nuclear power stations thus available were shown in a detailed manner in two reports [4] and [5], and evaluated in [6]. The majority of results ranges between neutron fluences of approx. $0.5 \cdot 10^{18}$ cm^{-2} and $6 \cdot 10^{18}$ cm^{-2} (E > 1 MeV). The extended range up to $5 \cdot 10^{19}$ cm^{-2} (E > 1 MeV) has been evidenced by measurements in the reactor pressure vessels of Obrigheim, Stade and Neckarwestheim 1.

(2) The evaluations made up to now were based on the search for a quantifiable dependence of the irradiation reaction on the chemical composition or other material and/or irradiation parameters [2], [7]. The irradiation reactions were quantified e.g. according to standards referenced in [1], [8] with respect to a transition-temperature shift, e.g. ΔT_{41}, referring to the difference in the indexes for the best-fit (average) curve for absorbed energies measured before and after the irradiation of specimens. The new edition of KTA 3203 does not intend to use transition-shift values, but to directly use RT_{NDTj} [1] or RT_{T0j} [9], i.e. the value describing the actual condition in dependence of the neutron fluence, which is to be considered in the safety analysis of the RPV for the material under consideration.

(3) **Figure B-1** shows the RT_{NDTj} or RT_{T0j} values experimentally determined for base materials and weld metals in the RPV beltline region of German nuclear power stations under operation except for the RPV weld metals of NPS Obrigheim and Stade which were sorted out because these weld metals have a clearly higher copper content compared to all other weld metals. Those RT_{NDTj} and RT_{T0j} values were taken for the curve which had been reported to the respective licensing authorities as a result of the irradiation surveillance programs. For materials with a percent by mass for nickel exceeding 1.1 % values are available only for a neutron fluence of $\Phi = 6 \cdot 10^{18}$ cm^{-2}, (E > 1 MeV).

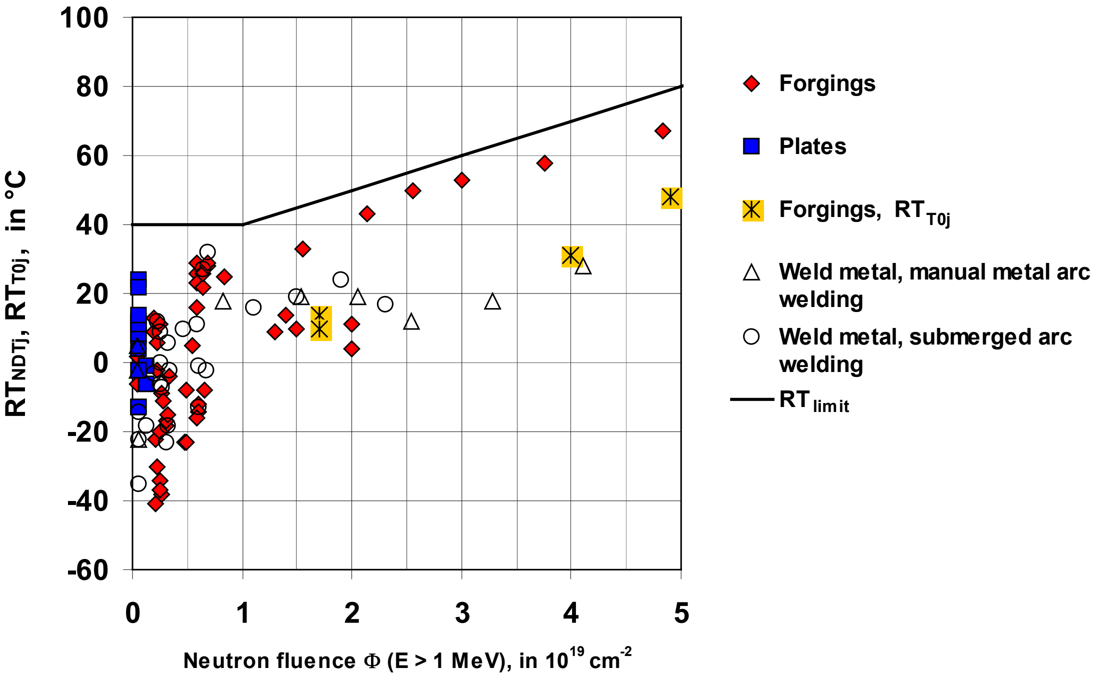


Figure B-1: RT_{NDTj}, RT_{T0j} as a function of neutron fluence, results obtained on base materials and weld metals from irradiation surveillance programs in German reactor RPV (BWR and PWR); only weld metals with percent by mass Cu ≤ 0.15 % and 0.05 % < Ni ≤ 1.7 %.

The definition

$$RT_{NDTj} = RT_{NDT} + \Delta T_{41} \quad \text{(B-1)}$$

was used in accordance with [1]. According to the ASME Code Case [9] the determination of RT_{T0j} was based on the reference temperature T_0 determined directly on irradiated fracture toughness specimens as per ASTM E-1921 (the index j was attached analogously to RT_{NDTj} for the respective irradiated condition)

$$RT_{T0j} = T_{0j} + 19\ K \quad \text{(B-2)}$$

B 3 Influences of alloying and accompanying elements

(1) Besides the fluence a variety of parameters influences the irradiation reaction. According to the state of science, at least qualitative evidence on the influence of some alloying and accompanying elements on RPV materials has been provided. These elements comprise copper, nickel and phosphorus, a fact which has been accounted for in standards dealing with the irradiation behaviour of materials.

(2) In Germany, percentage by mass of copper exceeding 0.18 % was only found in welded joints for which copper-coated welding wires had been used. Since the negative influence of copper on the irradiation behaviour has been evidenced, lower copper contents for base materials and weld metals were fixed in the respective material specifications.

(3) The effects of the nickel content on the irradiation reaction were found out relatively late, but have been ascertained worldwide in the meantime and accounted for in international rules and standards, e.g. by Regulatory Guide 1.99 Rev. 2 [8]. In Germany, nickel is an alloying element of all base materials and most of the weld metals used in the RPV beltline region. Nickel percentage by mass of approx. 0.7 % to 1 % was statistically confirmed with results obtained from German irradiation surveillance programs. In the past, nickel was added as alloying element with a percent by mass of up to 1.7 % to weld metals in order to increase their toughness properties. The considerably increased irradiation reaction thus obtained will be compensated by more favourable RT_{NDT} values at unirradiated condition for the range of neutron fluences approx. up to $6 \cdot 10^{18}$ cm^{-2} (E > 1 MeV) for which data are available from German nuclear power stations.

(4) The influence of phosphorus has also been recognized worldwide. The differences regarding the phosphorus content in materials in the beltline region of German RPV`s did not lead to a quantifiable differentiation regarding this accompanying element.

(5) For some other elements no differentiation can be made with respect to their influence on the irradiation reaction [10]. Therefore, no recognized evaluations are available for these elements. Such influences have been included, however, in the evaluated irradiation results.

B 4 Recorded area and confirmed area

(1) **Figure B-2** shows the percentage by mass of copper and nickel for the materials as per **Figure B-1**. From Figure B-2 it can be read that copper contents of 0.03 % up to 0.15 % have statistically been confirmed in sufficient number. As the influence of copper and nickel on the irradiation reaction, as far as quantifiable, increase with a rise in percent by mass, lower contents are also covered in the case of copper. A clear reduction of the nickel content implies the use of other materials which among certain circumstances will show different mechanical properties.

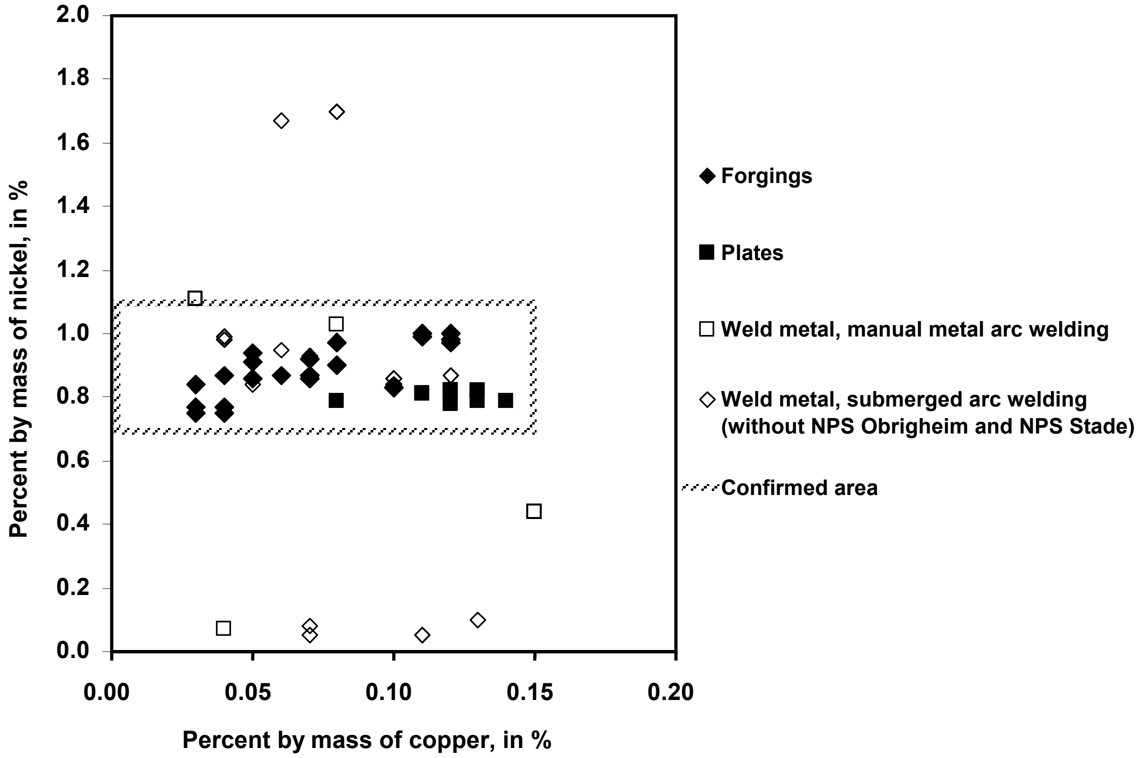


Figure B-2: Area of copper and nickel percent by mass covered by results obtained from RPV irradiation surveillance programs

(2) (2) It can be seen that at a lower percentage by mass of nickel (Ni < 0.7 %) **Figure B-1** shows no peculiarities. The stronger irradiation reaction known to be caused by high nickel contents (Ni = 1.7 %) will be compensated by the more favourable RT_{NDT} values at unirradiated condition for the range of neutron fluences approx. up to $6 \cdot 10^{18}$ cm^{-2} (E > 1 MeV) for which data are available from German nuclear power stations. For this reason, the weld metals are also below the RT_{limit} curve as per **Figure B-1**. Since no statistically evidenced values are available, the confirmed area at a nickel percent by mass of 1.1 % has been enveloped. The area thus confirmed is shown in **Figure B-2**.

B 5 RT_{limit} curve

B 5.1 Range of application of the RT_{limit} curve

(1) The range of application of the RT_{limit} curve (RT_{limit}) can be derived from the specified area which the materials represent subsequent to the evaluation of the results obtained from these materials. The percentage by mass of copper and nickel shall particularly be accounted for, however, materials fabrication and heat treatment shall also be adapted accordingly which is ensured by the specified strength and toughness values in accordance with KTA 3201.1 and KTA 3201.3 and shall be evidenced during acceptance testing.

(2) The German reactor pressure vessels which were not fabricated to comply with KTA Safety Standards 3201.1 and KTA 3201.3, nevertheless meet the essential strength and toughness requirements, e.g. with regard to the upper-shelf energy on transverse specimens; this is why the RT_{limit} curve encompasses these materials as shown in **Figure B-1**. In addition, the following limit values for copper and nickel percentage by mass shall not be exceeded:

Cu $\leq$ 0.15 %
Ni $\leq$ 1.1 %

For a nickel percent by mass exceeding 1.1 % and equal to or smaller than 1.7 % the RT_{limit} curve applies up to neutron fluence levels of up to $6 \cdot 10^{18}$ cm^{-2} (E > 1 MeV).

(3) In addition care shall be taken to ensure that the parameters neutron spectrum and irradiation temperature are comparable. As the irradiation temperatures for PWR and BWR are different, the temperature range of

approx. 275 °C < T < approx. 300 °C

can be considered to be confirmed.

(4) A review of foreign irradiation data [11], [12], [13] proved that the RT_{NDTj} values of those values which meet the aforementioned application requirements are also covered by the RT_{limit} value [6].

B 5.2 Determination of the RT_{limit} value

(1) **Figure B-1** shows that all RT_{NDTj} values of German RPV, regardless of whether BWR of PWR, forging or plate, 22 NiMoCr 3 7 or 20 MnMoNi 5 5, and all weld metals with a copper percent by mass equal to or less than 0.15 % are below a specified limit curve. **Figure 3-1** shows the reference temperature RT_{limit} thus defined.

(2) The RT_{limit} value can be presented with the following formulae:

$$RT_{limit} = 40\ °C \qquad \text{for } 0 < \Phi < 10^{19}$$

$$RT_{limit} = \left(\frac{\Phi}{10^{18}\,cm^{-2}} + 30 \right)\ °C \qquad \text{for } \Phi > 10^{19}$$

with the neutron fluence Φ, in cm^{-2} (E > 1 MeV).

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Figures

Figure B-1: RT_{NDTj}, RT_{T0j} as a function of neutron fluence, results obtained on base materials and weld metals from irradiation surveillance programs in German reactor RPV (BWR and PWR); only weld metals with percent by mass Cu $\leq$ 0.15 % and 0.05 % < Ni $\leq$ 1.7 %.

Figure B-2: Area of copper and nickel percent by mass covered by results obtained from RPV irradiation surveillance programs

Annex C (informative)

Changes with respect to previous edition 3/84 and explanations

(1) The restriction to plants designed and manufactured to KTA Safety Standard 3201 as laid down in the scope of issue 3/84 of this standard was not taken over. This restriction is not required for the specifications of the current issue.

(2) For the terms "Limit value of the reference temperature (RT_{limit})" and "Assessment fluence" new definitions were made.

(3) Sections 3 "General principles" and 6 "Testing and evaluation" were entirely revised and adapted to the state of knowledge, with section 6 being supplemented by a rule for evaluating the results obtained from irradiation surveillance programs. The basis for the revision was the evaluation of national and international irradiation results presented in Annex B. With the data now available it is possible to take the confirmed adjusted reference temperature as controlling value instead of the transition temperature shift ΔT_{41}. In addition, a RT_{limit} curve can be given now (Figure 3-1). The stipulations in sections 3 and 6 are adjusted to meet German NPS conditions and without further review can only be applied to materials represented by the data basis evaluated as per Annex B. For the same reason, the application of other rules for predicting the radiation reaction of materials is not purposeful.

(4) In connection with the changes made in section 6 figure 4-1 was not taken over.

(5) In section 5.4 "Specimen orientation and location"

- subdivision was made into clauses "General", "Base material" and "Weld metal",
- the stipulations referring to the HAZ were not taken over here and in Table 3-2, since materials represented by the data basis evaluated as per Annex B need not be considered separately. (see also e.g. K. Kußmaul, E. Roos, J. Föhl: "Research Project: Component Safety - An Essential Contribution to Component Safety", 23rd MPA Seminar held in Stuttgart on 1st/2nd of October 1997),
- the possibility of using fracture toughness test specimens was included,
- those tests belonging to the standard extent of testing as specified in KTA 3201.1 and KTA 3201.3 were not taken over any more.

(6) Section 6 "Testing and evaluation" was slightly revised.

(7) In addition

a) the structure of this safety standard was revised and the clauses ordered chronologically as to their application,

b) editorial changes and corrections were incorporated,

c) references to the current edition of the standards were made.