Safety Standards

of the
Nuclear Safety Standards Commission (KTA)

KTA 3203 (2017/11)

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

(Überwachung des Bestrahlungsverhaltens von Werkstoffen der Reaktordruckbehälter von Leichtwasserreaktoren)

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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, 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 objective to specify safety-related requirements, compliance of which provides the necessary precautions in accordance with the state of the art in science and technology against damage arising from the construction and operation of the facility (Sec. 7 para. 2 subpara. 3 Atomic Energy Act - AtG) in order to achieve the fundamental safety functions specified in the Atomic Energy Act and the Radiological Protection Ordinance (StrlSchV) and further detailed in the Safety Requirements for Nuclear Power Plants (SiAnf) as well as in the Interpretations on the Safety Requirements for Nuclear Power Plants.

(2) No. 2.1 of the Safety Requirements for Nuclear Power Plants, among other things, sets stringent requirements for the quality assurance and reliability of manufacturing. In no. 3.1 furthermore the use of qualified materials and manufacturing as well as the assurance and maintenance of the quality features during manufacturing is required. Safety requirement no. 3.4 (1) requires, among other things, that the reactor coolant pressure boundary shall be designed, located and operated such that the occurrence of rapidly propagating cracks and of brittle fracture need not be postulated. According to the requirement 5 (3) a documentation shall be established showing that the current condition of the safety-relevant measures and equipment fulfils the applicable requirements. Sub-para 3.2 (3) of Interpretation I-2 requires a monitoring program with suspended accelerated irradiation capsules to characterize the material properties changed due to irradiation. KTA safety standard 3203 defines provisions to be made to meet these requirements within their scope of application. For primary circuit components the stipulations of the aforementioned safety requirements 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.

and

KTA 3206 Break Preclusion Verifications for Pressure-Retaining Components in Nuclear Power Plants

(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, and to confirm or define anew the location of the fracture toughness curve to be used as laid down in the brittle fracture analysis to KTA 3201.2.

1 Scope

This safety standard shall apply to the monitoring of irradiation behaviour of belt-line 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) Core belt line region

The core belt line 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 pre-calculated 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 to the RT_{NDT} concept 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 (transverse specimen with V-notch) shall normally exhibit at least 0.9 mm lateral expansion and not less than 68 J impact 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 (transverse specimen with V-notch) 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 impact energy of 68 J and 0.9 mm lateral expansion shall normally be obtained from the impact-energy versus temperature curve and the lateral expansion versus temperature curve developed from the minimum values obtained from all specimens.

(10) Reference temperature RT_{NDT}, adjusted ($RT_{NDT\,j}$)

This means the reference temperature as adjusted in the RT_{NDT} concept for irradiation effects by adding to the reference temperature of the unirradiated material the transition temperature shift ΔT_{41} to obtain:

$$RT_{NDT\,j} = RT_{NDT} + \Delta T_{41} \quad (2\text{-}1)$$

(11) Directly determined reference temperature RT_{T0},

This means the reference temperature RT_{T0} as derived in the master curve concept from the reference temperature T_0 of the irradiated RPV material to obtain:

$$RT_{T0} = T_0 + 19.4\ K + M \quad (2\text{-}2)$$

The temperature allowance M considers the influence including the statistical variance of the type of specimen, type of material (base metal or weld metal), material variability, thickness and number of specimens on T_0.

(12) Reference temperature RT_{T0}, adjusted ($RT_{T0\,j}$)

This means the reference temperature as adjusted in the master curve concept for irradiation effects from the reference temperature $T_{0\,u}$ to obtain:

$$RT_{T0\,j} = T_{0\,u} + k \cdot \Delta T_{41} + 19.4\ K + M \quad (2\text{-}3)$$

The temperature allowance M considers the influence including the statistical variance of the type of specimen, type of material (base metal or weld metal), material variability, thickness and number of specimens on T_0.

The factor k describes the correlation between the transition temperature shift ΔT_{41} and transition temperature shift ΔT_0 of the master curve [1]. For German RPV materials a value k = 1.0 [2] applies.

(13) Reference temperature T_0, irradiated condition

The reference temperature T_0 is the temperature determined to ASTM E1921 for the irradiated condition within the master curve concept.

(14) Reference temperature T_0, unirradiated condition($T_{0\,u}$)

The reference temperature $T_{0\,u}$ is the temperature determined to ASTM E1921 for the unirradiated condition within the master curve concept.

(15) Authorized inspector

The authorized inspector for the tests and inspections to be conducted in accordance with this safety standard is the authorized inspector called in by the licensing or supervisory authority pursuant to Section 20 of the Atomic Energy Act. The inspections/reviews required by this safety standard shall be performed on the basis of applications made by the competent authority.

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

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

3 General Principles

3.1 Purpose of the irradiation surveillance program

(1) 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 during operation up to the assessment fluence.

(2) By means of the results obtained within the irradiation program the location of the fracture toughness curve to be used within the brittle fracture analysis to KTA 3201.2 shall be confirmed or be determined anew either

a) indirectly by using accelerated-irradiation impact specimens for determining the transition temperature shift ΔT_{41},

or

b) directly by using accelerated-irradiation fracture toughness specimens for determining the reference temperature T_0 to the master curve concept to ASTM E1921.

(3) The location of the fracture toughness curve shall be determined by means of the reference temperature $RT_{NDT\,j}$ using the transition temperature shift ΔT_{41}.

(4) Alternatively to the reference temperature $RT_{NDT\,j}$ the use of the reference temperature RT_{T0} or $RT_{T0\,j}$ is permitted. The temperature allowance M shall be determined appropriately in dependence of the governing variables and their statistical variance and be justified.

Notes:

(1) The alternative use of the reference temperature T_0 of the master curve concept increased by 19.4 K to determine the location of the fracture toughness curve is described in the Code Cases N-851 (Section XI) and N-631 (Section III) of the ASME Code. Information on the use of the master curve concept within a deterministic brittle fracture analysis and for the determination of a suitable temperature allowance M can be found e.g. in IAEA Technical Reports Series No. 429.

(2) Further information of the use of the master curve concept can be found e.g. in [3] to [9].

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 less 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**. The adherence to the limit value RT_{limit} shall be confirmed using $RT_{NDT\,j}$ or RT_{T0} or $RT_{T0\,j}$ as a result of an irradiation program in accordance with **Table 3-1**, **Table 3-2** or **Table 3-3** respectively. The adjusted reference temperature $RT_{NDT\,j}$ or RT_{T0} or $RT_{T0\,j}$ thus determined may be taken for the proof of safety against brittle fracture alternatively to the value of RT_{limit}.

(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**. The adherence to the limit value RT_{limit} shall be confirmed to cover $RT_{NDT\,j}$ or RT_{T0} or $RT_{T0\,j}$ as a result of an irradiation program in accordance with **Table 3-4**, **Table 3-5** or **Table 3-6** respectively. The adjusted reference temperature $RT_{NDT\,j}$ or RT_{T0} or $RT_{T0\,j}$ thus determined may be taken for the proof of safety against brittle fracture alternatively to the value of RT_{limit}.

(4) At a neutron fluence equal to or less than 1 • 10^{19} cm^{-2} (for neutron energies E > 1 MeV) in the maximum irradiated region of the ferritic inner wall of the RPV, no characteristic values determined on irradiated tensile specimens are required for materials in the confirmed area to **Figure B-2**, see footnote 1 in **Table 3-1** and footnote 2 in **Table 3-3**.

Notes:

(1) From the results obtained on irradiated tensile specimens from German PWR and BWR reactor pressure vessels as well as from the results obtained within the research project CARINA, the influence of neutron irradiation in this fluence area on the material strength properties is sufficiently known.

(2) As regards the base metal and weld metals with maximum percentage by mass of Cu ≤ 0.15% and Ni ≤ 1.1% there will be a moderate increase of the yield strength in this fluence area by up to approx. 80 MPa.

(5) Where the reference temperature RT_{T0} determined on directly irradiated fracture mechanics specimens is selected as safety concept as per (2) or (3), ASTM E1921 additionally requires, in deviation of (4), for both the determination of the size conditions for valid characteristic values and for the initiation of a fatigue crack in the fracture mechanics specimens, the characteristic values determined on irradiated tensile specimens; see **Table 3-2** and **Table 3-5**.

(6) 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	V-notch impact specimens		Tensile specimens 1)		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

1) Irridiated tensile specimens are not required for materials within the confirmed area of **Figure B-2**.

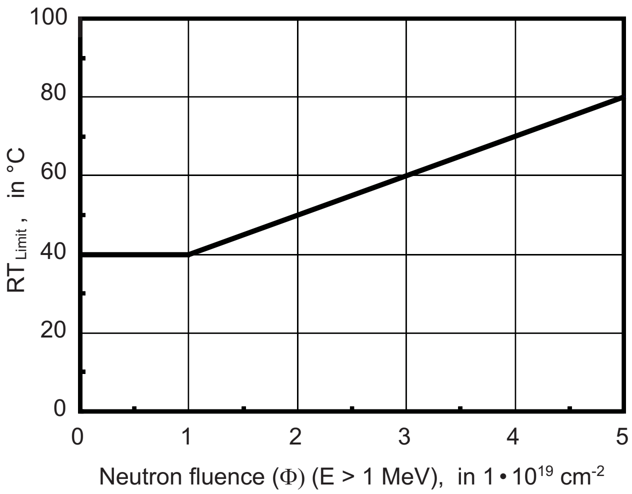
Table 3-1: Number of test specimens for assessment fluences equal to or less than 1 • 10^{19} cm^{-2} at neutron energies E > 1 MeV if the RT_{NDT} concept is used

No. of specimen set	Fracture mechanics specimens 1)		Tensile specimens		Time of withdrawal
	BM	WM	BM	WM	
1	10	10	3	3	unirradiated
2	10	10	3	3	≈ 50 % AF
3	10	10	3	3	≥100 % AF

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

1) The number of fracture mechanics specimens indicated is recommended. The requirements of ASTM E1921 for a valid determination of T_0 shall be adhered to.

Table 3-2: Number of test specimens for assessment fluences equal to or less than 1 • 10^{19} cm^{-2} at neutron energies E > 1 MeV if the master curve concept is used for determining the reference temperature RT_{T0}



This limit value applies to neutron fluences (at neutron energies E > 1 MeV) equal to or greater than 1 • 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 • 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)

No. of specimen set	V-notch impact specimens		Fracture mechanics specimens 1)		Tensile specimens 2)		Time of withdrawal
	BM	WM	BM	WM	BM	WM	
1	12	12	10	10	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

1) The number of fracture mechanics specimens indicated is recommended. The requirements of ASTM E1921 for a valid determination of T_0 shall be adhered to.

2) Irridiated tensile specimens are not required for materials within the confirmed area of **Figure B-2**.

Table 3-3: Number of test specimens for assessment fluences equal to or less than 1 • 10^{19} cm^{-2} at neutron energies E > 1 MeV if the master curve concept is used for determining the adjusted reference temperature $RT_{T0\ j}$

No. of specimen set	V-notch impact 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 3-4: Number of test specimens for assessment fluences greater than 1 • 10^{19} cm^{-2} at neutron energies E > 1 MeV if the RT_{NDT} concept is used

No. of specimen set	Fracture mechanics specimens [1)]			Tensile specimens			Time of withdrawal
	BM I	BM II	WM	BM I	BM II	WM	
1	10	10	10	3	3	3	unirradiated
2	10	10	10	3	3	3	≈ 50 % AF
3	10	10	10	3	3	3	≥ 100 % AF

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

1) The number of fracture mechanics specimens indicated is recommended. The requirements of ASTM E1921 for a valid determination of T_0 shall be adhered to.

Table 3-5: Number of test specimens for assessment fluences greater than 1 • 10^{19} cm^{-2} at neutron energies E > 1 MeV if the master curve concept is used for determining the adjusted reference temperature RT_{T0}

No. of specimen set	V-notch impact specimens			Fracture mechanics specimens [1)]			Tensile specimens			Time of withdrawal
	BM I	BM II	WM	BM I	BM II	WM	BM I	BM II	WM	
1	12	12	12	10	10	10	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

1) The number of fracture mechanics specimens indicated is recommended. The requirements of ASTM E1921 for a valid determination of T_0 shall be adhered to.

Table 3-6: Number of test specimens for assessment fluences greater than 1 • 10^{19} cm^{-2} at neutron energies E > 1 MeV if the master curve concept is used for determining the adjusted reference temperature $RT_{T0\,j}$

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 belt-line 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 encapsulated 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) arrangement of individual specimens, neutron detectors and temperature monitors in the irradiation capsule,

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 for design approval 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 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, their planned target fluence 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 refueling.

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 core belt line 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 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 11.2.2.1 (1) of KTA 3201.3 under the same conditions as the original weld of the RPV.

(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 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 weld of the RPV to be monitored.

(4) The heat treatments of the test coupon shall correspond to those of the RPV 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 **Tables 3-1** to **3-3**) or the two adjacent base metals and the weld metal (see **Tables 3-4** to **3-6**). 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 in addition to the sets of specimens selected according to 4.4 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 specimen-taking plan, see clause 4.1 (1) (b).

5.4.2 Base metal

(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 mechanics 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 mechanics 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.

Note:

Except for the neutron fluence detectors (Section 6.3) the testing of specimens performed at a later date does not lead to a reduction in technical preciseness provided that the specimen retention was proved to be appropriate.

(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.

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

(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.

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 25456-1.

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 25456-2	$^{54}Fe(n,p)^{54}Mn$
Niobium to DIN 25456-4	$^{93}Nb(n,n')^{93}Nb^{m}$
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

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, if required by Section 3, for 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 as well as percentage elongation before reduction A_q 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 in the case of irradiated specimens because of the annealing effect.

b) Impact test specimens (with V-notch) for unirradiated sets of specimens for determining the complete impact energy-versus-temperature curves including lateral expansion and ductile fracture percentage, with the curves beginning at the lower shelf, characterized by a ductile percentage not to exceed 5% of the fracture area, up to the temperature corresponding to the long-term irradiation temperature of the specimens.

c) Where the RT_{NDT} concept as well as the master curve concept with determination of the adjusted reference temperature $RT_{T0\,j}$ is used, in addition to a) and b) impact test specimens (with V-notch) for irradiated sets of specimens for determining the complete impact energy-versus-temperature curves including lateral expansion and ductile fracture percentage, with the curves beginning at the lower shelf, characterized by a ductile percentage not to exceed 5% of the fracture area, up to the temperature corresponding to the long-term irradiation temperature of the specimens.

d) Where the master curve concept to determine the adjusted reference temperature $RT_{T0\,j}$ is used, in addition to the specimens to a), b) and c), fracture mechanics specimens to determine the reference temperature T_0 in the unirradiated condition.

e) Where the master curve concept to directly determine the reference temperature is used, in addition to a) and b) fracture mechanics specimens to determine the reference temperature T_0 in the irradiated condition.

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 ISO 6892-1 and DIN EN ISO 6892-2 with a specimen shape to DIN 50125 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 ISO 148-1 on specimens with V-notch using a striker with a radius of 2 mm (KV_2); load-time or load-path plots shall be recorded and evaluated.

(4) Where the toughness properties are checked by examining irradiated fracture mechanics test specimens, the fracture mechanics tests may be performed, e.g. to ASTM E1921.

6.4.3 Determination of material characteristics

(1) The following material properties shall be determined on specimens to be tested according to clause 6.4.1:

a) on tensile specimens: the yield strength R_{eH} or proof stress $R_{p0,2}$, tensile strength R_m, elongation at fracture A 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) on notched bar impact specimens: the transition temperature shift from average (best-fit) curves at an impact energy of 41 J and derived from that ΔT_{41},

c) on fracture mechanics specimens: J_c and derived from that K_{Jc} and T_{T0} to ASTM E1921.

Note:

J_c is the J-integral at the point of onset of cleavage fracture determined for the elastic-plastic material behaviour. K_{Jc} is the elastic-plastic stress intensity factor derived from J_c . The definition and determination of these values is laid down in ASTM E1921.

(2) As regards the use of the values determined by tensile testing for the testing and evaluation of the fracture mechanics specimens as per **Tables 3-2**, **3-3**, **3-5**, and **3-6**, the test temperatures for tensile testing in the unirradiated and in the irradiated condition may be adapted to meet the requirements of ASTM E1921. The suitably adapted test temperatures shall be presented to the supervising authority for approval prior to performing the tensile tests.

(3) Where the master curve concept is used, the modulus of elasticity is additionally required.

6.4.4 Evaluation of the material characteristic values

(1) From the material characteristic values determined to clause 6.4.3 the following shall be determined:

a) where the RT_{NDT} concept is used: the adjusted reference temperature $RT_{NDT\,j}$,

b) where the master curve concept is used alternatively: the adjusted reference temperature $RT_{T0\,j}$ or the directly determined reference temperature RT_{T0},

(2) The adjusted reference temperature $RT_{NDT\,j}$ or $RT_{T0\,j}$ or RT_{T0} 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 $RT = A + B \cdot \Phi^n$ shall preferably be used. Where values are available from only one irradiated specimen set (specimen set 2 in **Tables 3-1** to **3-6**), a qualified extrapolation is permitted to obtain the target neutron fluence value of the second irradiated specimen set, e.g. by using the NRC Regulatory Guide 1.99 Rev. 2, Position 1 (on the basis of Cu- and Ni-content) until the values from the second specimen set (specimen set 3 in **Tables 3-1** to **3-6**) have been determined. The adjusted reference temperature shall be predicted for the obtained actual fluence of specimen set 2 and the target fluence of specimen set 3, and in case of major discrepancy of specimen set 2 be adapted in a suitable manner to the test results of specimen set 2 for both specimens sets.

(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) $RT_{NDT\,j} \leq RT_{limit}$ or

$RT_{T0} \leq RT_{limit}$ or

$RT_{T0\,j} \leq RT_{limit}$.

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

(5) Where with an increase in neutron fluence lower values for $RT_{NDT\ j}$ or RT_{T0} or $RT_{T0\ j}$ are obtained, the highest value determined for $RT_{NDT\ j}$ or RT_{T0} or $RT_{T0\ j}$ shall be used to verify that $RT_{NDT\ j} \leq RT_{limit}$ or $RT_{T0} \leq RT_{limit}$ or $RT_{T0\ j} \leq RT_{limit}$.

(6) Where the determined reference temperature $RT_{NDT\ j}$ or RT_{T0} or $RT_{T0\ j}$ exceeds RT_{limit}, the brittle fracture analysis for the reactor pressure vessel shall be performed to KTA 3201.2, section 7.9 using the value determined, or, if necessary, the safety of the reactor pressure vessel shall be verified by other means using the value determined.

Note:

The ASME Code Case N-830 (Section XI) describes an additional possibility of determining a deterministic fracture toughness curve directly derived from the master curve for pressure vessels of class 1, see also [10].

(7) Where the upper-shelf impact energy is less than 68 J (individual value), the safety of the reactor pressure vessel shall be verified to KTA 3201.2, section 7.9 or by other means, if required.

7 Retention of specimens

All tested and untested specimens as well as the reserve material shall be retained until final cessation of power operation of the plant.

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 to contain a table of contents.

Annex A

Regulations and literature 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 Article 2 (2) of the law dated July 20th, 2017 (BGBl. I 2017, no. 52, p. 2808)
StrlSchV		Ordinance on the Protection against Damage and Injuries Caused by Ionizing Radiation (Radiation Protection Ordinance) dated 20th July 2001 (BGBl. I p. 1714; 2002 I p. 1459), last amended in accordance with article 10 by article 6 of the law dated 27th January 2017 (BGBl. I p. 114, 1222)
SiAnf	(2015-03)	Safety Requirements for Nuclear Power Plants (SiAnf) as Promulgated on March 3rd 2015 (BAnz AT 30th March 2015 B2)
Interpretations	(2015-03)	Interpretations of the Safety Requirements for Nuclear Power Plants of November 22nd 2012, as Amended on March 3rd 2015 (BAnz AT 30th March 2015 B3)
KTA 3201.1	(2017-11)	Components of the Reactor Coolant Pressure Boundary of Light Water Reactors; Part 1: Materials and Product Forms
KTA 3201.2	(2017-11)	Components of the Reactor Coolant Pressure Boundary of Light Water Reactors; Part 2: Design and Analysis
KTA 3201.3	(2017-11)	Components of the Reactor Coolant Pressure Boundary of Light Water Reactors; Part 3: Manufacturing
KTA 3201.4	(2016-11)	Components of the Reactor Coolant Pressure Boundary of Light Water Reactors; Part 4: Inservice Inspection and Operational Monitoring
KTA 3206	(2014-11)	Verification Analysis for Rupture Preclusion for Pressure Retaining Components in Nuclear Power Plants
DIN EN ISO 148-1	(2017-05)	Metallic materials - Charpy pendulum impact test - Part 1: Test method (ISO 148-1:2016); German version EN ISO 148-1:2016
DIN EN ISO 6892-1	(2017-02)	Metallic materials - Tensile testing - Part 1: Method of test at room temperature (ISO 6892-1:2016); German version EN ISO 6892-1:2016
DIN EN ISO 6892-2	(2011-05)	Metallic materials - Tensile testing - Part 2: Method of test at elevated temperature (ISO 6892-2:2011); German version EN ISO 6892-2:2011
DIN 25456-1	(1999-10)	Neutron fluence measurements; Part 1: Fluence determination of fast neutrons with activation and fission detectors
DIN 25456-2	(1999-10)	Neutron fluence measurements; Part 2: Fluence determination of fast neutrons with iron-activation detectors
DIN 25456-4	(1999-10)	Neutron fluence measurements; Part 4: Fluence determination of fast neutrons with niobium-activation detectors
DIN 50125	(2016-12)	Testing of metallic materials - Tensile test pieces
SEP 1325	(1982-12)	Drop-weight test to W.S. Pellini
ASTM E1921	(2017)	ASTM E1921-17a, Standard Test Method for Determination of Reference Temperature, T_0, for Ferritic Steels in the Transition Range, ASTM International, West Conshohocken, PA, 2017
ASME Code Case N-631		Use of Fracture Toughness Test Data to Establish Reference Temperature for Pressure Retaining Materials, Other Than Bolting, Class 1 Vessels; Approval Date: 24th September 1999
ASME Code Case N-830		Direct Use of Master Fracture Toughness Curve for Pressure-Retaining Materials of Class 1 Vessels; Approval Date: 4th September 2014
ASME Code Case N-851		Alternative Method for Establishing the Reference Temperature for Pressure Retaining Materials; Approval Date: 5th November 2014

IAEA TRS 429	Guidelines for Application of the Master Curve Approach to Reactor Pressure Vessel Integrity in Nuclear Power Plants; Technical Reports Series No. 429, International Atomic Energy Agency, Vienna, 2005
US NRC Regulatory Guide 1.99	Radiation Embrittlement of Reactor Vessel Materials, Revision 2; Mai 1988

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(Critical examination of the Master Curve approach with regard to its application in German nuclear power plants, RS Project 1501239 of BMWi, Fraunhofer IWM, Freiburg, 9th March 2005)

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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 belt-line 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 $RT_{NDT\ j}$ [1] or $RT_{T0\ j}$ [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 $RT_{NDT\ j}$ and $RT_{T0\ j}$ values experimentally determined for base materials and weld metals in the RPV belt-line 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 $RT_{NDT\ j}$ and $RT_{T0\ j}$ 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).

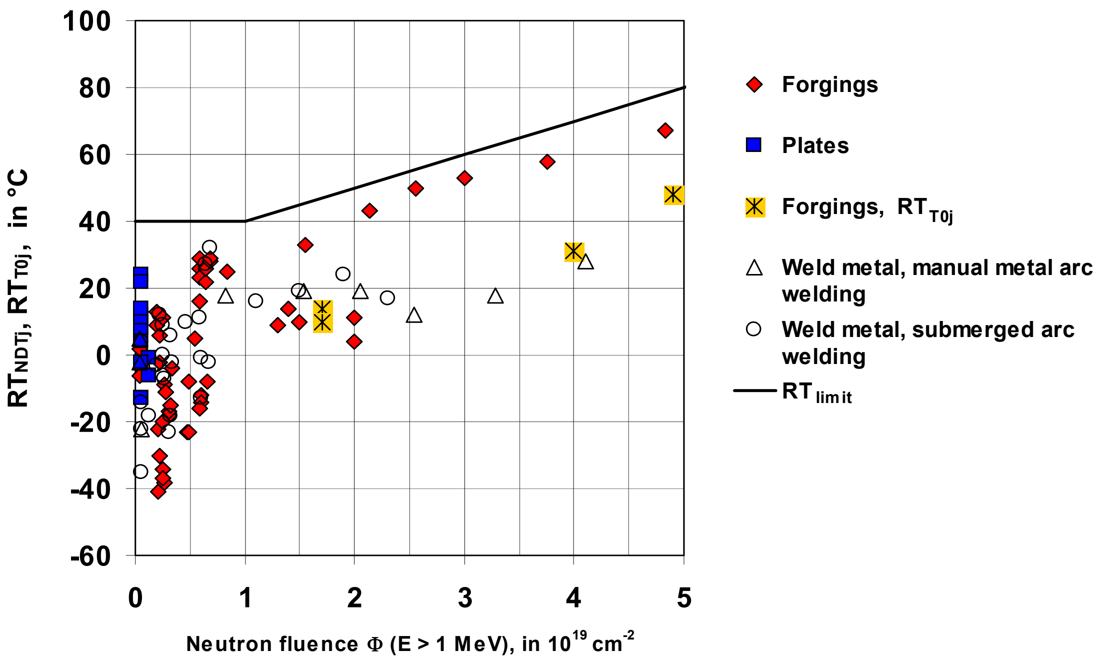

Figure B-1: $RT_{NDT\ j}$, $RT_{T0\ j}$ as a function of neutron fluence, results obtained on base materials and weld metals from irradiation surveillance programs in German reactor RPV (BWR and PWR); only weld metals with percent by mass of Cu ≤ 0.15 % and 0.05 % < Ni ≤ 1.7 %.

The definition

$$RT_{NDT\,j} = RT_{NDT} + \Delta T_{41} \qquad \text{(B-1)}$$

was used in accordance with [1]. According to the ASME Code Case [9] the determination of $RT_{T0\,j}$ was based on the reference temperature T_0 determined directly on irradiated fracture toughness specimens as per ASTM E1921 (the index j was attached analogously to $RT_{NDT\,j}$ for the respective irradiated condition)

$$RT_{T0\,j} = T_{0\,j} + 19\text{ K} \qquad \text{(B-2)}$$

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 • 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.

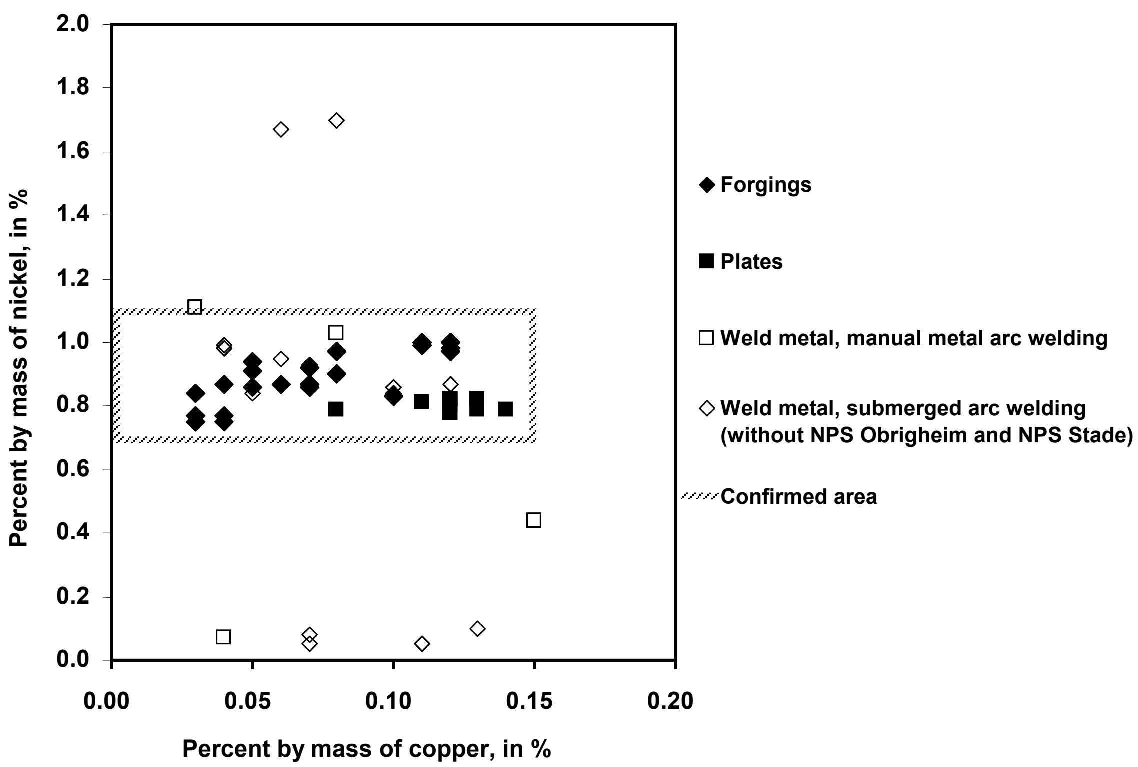

Figure B-2: Area of copper and nickel percentage by mass covered by results obtained from RPV irradiation surveillance programs

(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 impact 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 ≤ 0.15 %

Ni ≤ 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 $RT_{NDT\,j}$ 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 $RT_{NDT\,j}$ 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 percentage 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

Annex C (informative)

Changes with respect to previous edition 2001-06 and explanations

(1) The section “Fundamentals” was adapted in paragraph 1 to the formulation obligatory for all KTA safety standards. Paragraph 2 was supplemented to include stipulations from the “Safety Requirements for Nuclear Power Plants” (SiAnf) and from the “Interpretations on the Safety Requirements for Nuclear Power Plants”.

(2) By supplements made in paragraph 4 of the section “Fundamentals”, in section 3.1 and in section 5.3 the objectives of the irradiation program were put more precisely.

(3) In Section 2 “Definitions“, the following supplements were made:

a) Definitions relating to the reference temperature of the master curve concept were added which in connection with the supplements in clauses 6.4.1, 6.4.3 and 6.4.4 specify the basic procedure for the use of the master curve concept conforming to KTA 3201.2 (2013-11). Detailed approaches for the use of the master curve concept will be specified within the supervisory procedures.

b) The definition of „Authorized inspector“ was supplemented to conform to the current editions of KTA safety standards.

(4) In sections 3.1 and 3.2 stipulations were added relating the use of the reference temperature to the master curve concept as well as to the extent of specimens required in these cases.

(5) With today’s excellent knowledge the influence of neutron irradiation on the mechanical properties is sufficiently known for materials in the confirmed alloying range as shown in Figure B-2 at limited fluences of up to $1 \times 10^{19}/cm^2$. Therefore, clause 3.2 (4) as well as footnote 1 in Table 3-1 and footnote 2 in Table 3-3 and consequently the adaptation in clause 6.4.1 a) were supplemented to state that irradiated tensile specimens are not required in this defined area. This confirmed area corresponds to the constant range of RT_{limit} of 40 °C in Figure 3-1. In addition, an orientation value for an increase of the yield strength was given in the note to clause 3.2 (4).

(6) In new clause 3.2 (5) and with Tables 3-2 and 3-5 it was clarified that in case of a direct determination of RT_{T0} with irradiated specimens, ASTM E1921 requires the results of irradiated tensile specimens to determine the parameters for fracture mechanics tests.

(7) Clause 4.5 (2) was put more precisely to state that the given neutron fluences are planned target fluences to be obtained with the irradiated specimens.

(8) Clause 6.1 (2) was clarified by including a note to state that except for the neutron fluence detectors (section 6.3) the testing of specimens performed at a later date than after the expiration of one year does not lead to a reduced technical preciseness provided that the specimen retention was proved to be appropriate.

(9) In clause 6.4.4 (2) the exponential function for RT, applicable to $RT_{NDT\ j}$, $RT_{T0\ j}$ and RT_{T0} and therefore formulated without index, was corrected. In addition, a new text was included to state that for the German RPV materials a qualified extrapolation of the values of the first irradiated specimen set is permitted to obtain the target neutron fluence value of the second irradiated specimen set by using the NRC Regulatory Guide 1.99 Rev. 2, Position 1 (on the basis of Cu- and Ni-content), as long as the values from the second specimen set are not available.

(10) The requirements in clauses 6.4.4 (6) and (7) were supplemented and put more precisely for the case where deviations occur.

(11) In Section 7 the retention times of specimens were put more precisely.

(12) The complete standard was adapted to the current state of standardization in which case the definitions were also adapted to those of the current standards.

(13) At several locations editorial changes were made.

(14) The normative references in Annex A were updated and supplemented.