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Comparison of PWR and WWER RPV integrity and lifetime approaches

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COMPARISON OF PWR AND WWER RPV INTEGRITY AND LIFETIME APPROACHES

Milan Brumovský

Joint ICTP/IAEA Workshop on Effects of Mechanical Properties and Mechanisms Governing the Irradiation-induced Embrittlement of Pressure Vessel Steels

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CONTENT

INTRODUCTION

- INTEGRITY EVALUATION OF RPVs ARE USUALLY FULLY LEAD BY PTS ANALYSES
- THIS PRESENTATION WILL DEAL ONLY WITH A DETERMINISTIC APPROACH
- PWR ANALYSES ARE BASED MOSTLY ONY ASME/RSE-M/KTA CODES
- VVER ANALYSES ARE PERFORMED ACCORDING TO RUSSIAN MRKR-SKhR-2004 AND VERLIFE

Standards Currently Applicable for RPV Integrity Assessment for WWER

- **Unified Procedure for Lifetime Assessment of Components and Piping in VVER NPPs, VERLIFE, ver. 2008** (prepared within the frame of VERLIFE project of the 5th Framework Programme of the EU) – **in what follows, VERLIFE approach is mostly presented**
- **Guidelines on Pressurized Thermal Shock Analysis for WWER Nuclear Power Plants, Revision 1,** IAEA-EBP-WWER-08 (Rev. 1), IAEA, Vienna, 2006
- **Standards for Strength Evaluation of Component and Piping of Nuclear Power Plants,** PNAE G-7 002-86 (in Russian)
- **Methodology of Determination of the Residual Lifetime of the Reactor Pressure Vessels of WWER Reactors During Operation, MRK-SChR-2004"** (in Russian)

INTRODUCTION

- ALL APPROACHES ARE BASED ON APPLICATION OF FRACTURE MECHANICS APPROACH
- DIFFERENCES CAN BE FOUND IN:
  - DEFINITION OF CHARPY TRANSITION TEMPERATURE
  - DESIGN FRACTURE TOUGHNESS CURVES
  - USE OF TRANSITION TEMPERATURES
  - EVALUATION OF RADIATION DAMAGE
  - POSTULATED DEFECTS AND GROUNDS FOR THEIR SIZE, TYPE, SHAPE

DEFINITION OF CHARPY TRANSITION TEMPERATURE

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PWR ACCORDING TO ASME:

RT_{NDT} BASED ON DWT AND CHARPY TESTS

VVER ACCORDING TO PNAEG:

critical temperature of brittleness is a basis for an assessment of resistance against brittle failure. This critical temperature of brittleness, T_K, is determined using notch toughness testing of Charpy-V type specimens, only. In principle, this temperature is defined as a temperature, at which the mean value from 3 notch toughness tests is equal to a criterial value $(KCV)_c$ which is dependent on the yield strength ($R_{p0.2}$) of the material:

$R_{p0.2}$ [MPa]	$(KCV)_c$ [J.cm^{-2}]	$(KV)_c$ [J]
less than 300	30	24
300–400	40	32
400–550	50	40
550–700	60	48

At the same time, at a temperature equal to T_k + 30°C the following supplementary requirements must be fulfilled:

$$KCV \geq 1.5\ (KCV)_c \qquad (10)$$
$$(KCV)_{min} \geq 0.7 \times 1.5\ (KCV)_c = 1.05\ (KCV)_c$$
$$(\text{fracture appearance})_{min} \geq 50\ \%\ (\text{fibrous fracture, }\%)$$

DEFINITION OF CHARPY TRANSITION TEMPERATURE

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Differences between these critical temperatures, as determined experimentally for Types 15Kh2MFA and 15Kh2NMFA steel and ASTM A 533-B steel are:

$$\delta T = RT_{NDT} - T_k = \pm 10^{o}C \qquad (11)$$

The brittle to ductile transition temperature (critical temperature of brittleness) of the WWER pressure vessel materials is time or use dependent, since many damaging mechanisms can affect it, and can be expressed in the form:

$$T_k = T_{k0} + \Delta T_F + \Delta T_T + \Delta T_N \qquad (12)$$

where

T_K is the instant critical temperature of brittleness
T_{k0} is the initial critical temperature of brittleness
ΔT_F is the shift of critical temperature due to radiation embrittlement
ΔT_T is the shift of critical temperature due to thermal ageing
ΔT_N is the shift of critical temperature due to cyclic damage

DEFINITION OF CHARPY TRANSITION TEMPERATURE

The transition temperature shift due to radiation embrittlement (ΔT_F) can be expressed as

$$\Delta T_F = A_F \,.\, (F \times 10^{-22})^{1/3} \qquad (13)$$

where

A_F is the radiation embrittlement coefficient
F is the neutron fluence with energies greater than 0.5 MeV.

The shift ΔT_N represents the changes in the material properties caused by low-cycle fatigue damage. All transients are considered, including heatup and cooldown, pressure testing, scram, etc. For WWER pressure vessel materials, the Code provides the following formula to be used in the calculations:

$$\Delta T_N = 20 \,.\, A \; [^{\circ}C] \qquad (16)$$

where A is the usage factor from the fatigue calculations, which means that the maximum shift due to cyclic damage is equal to + 20°C. This shift is, of course, only taken into account in locations with high stress concentrators, where a high usage factor is obtained - i.e. mostly for nozzles.

DESIGN FRACTURE TOUCHNESS CURVES

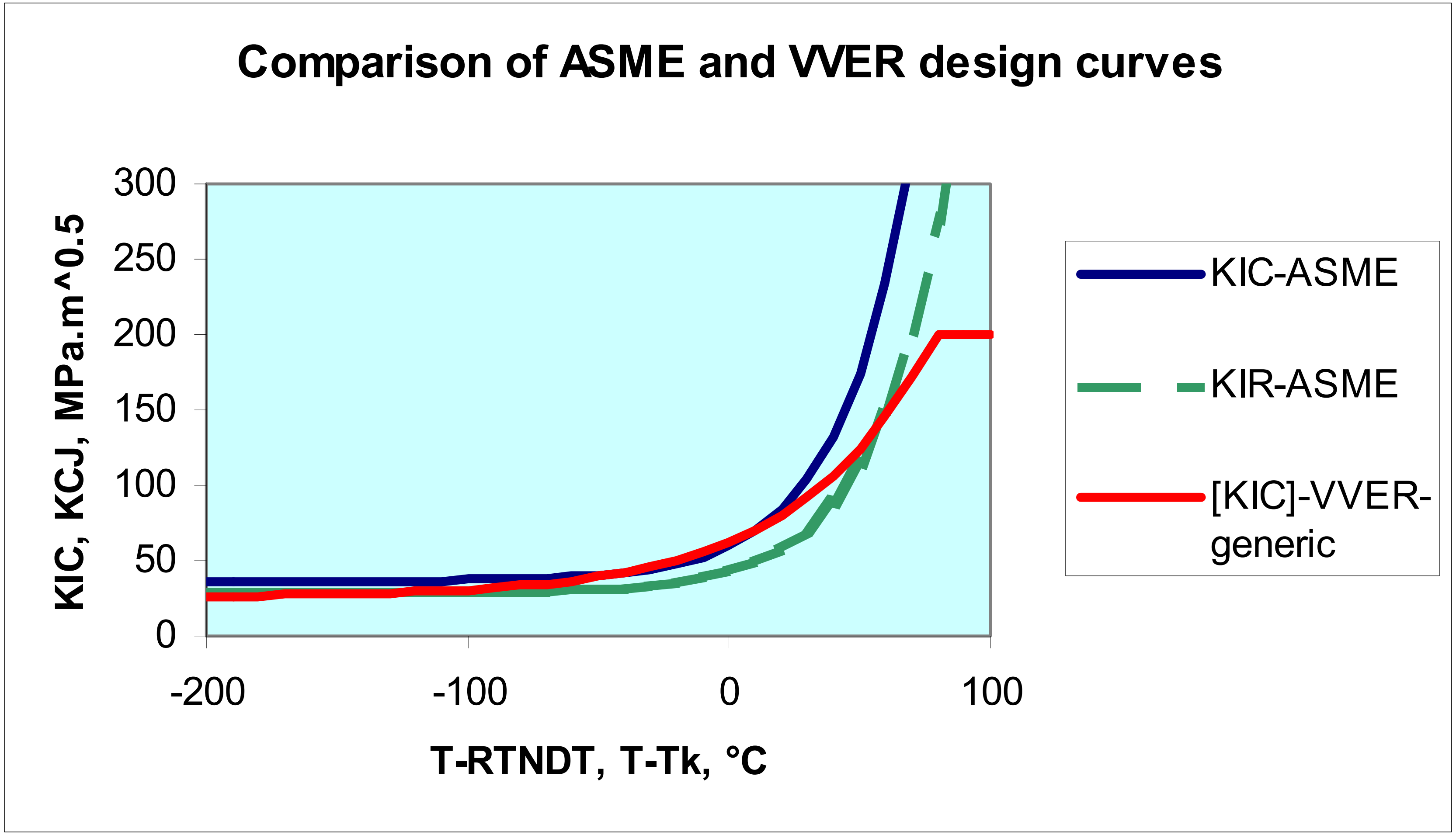
PWR and BWR:

$$K_{IC}(T-RT_{NDT}) = \min\{36.5+3.1\exp[0.036(T-RT_{NDT}+55.5)];\ 220\ \mathrm{MPa.m}^{0.5}\}$$

WWER (generalised curve) :

$$[K_{IC}\ (T-T_k)] = \min\{\ 26 + 36\exp[0.020\ (T-T_k)];\ 200\ \mathrm{MPa.m}^{0.5}\}$$

DESIGN FRACTURE TOUGHNESS CURVES



DESIGN FRACTURE TOUGHNESS CURVES

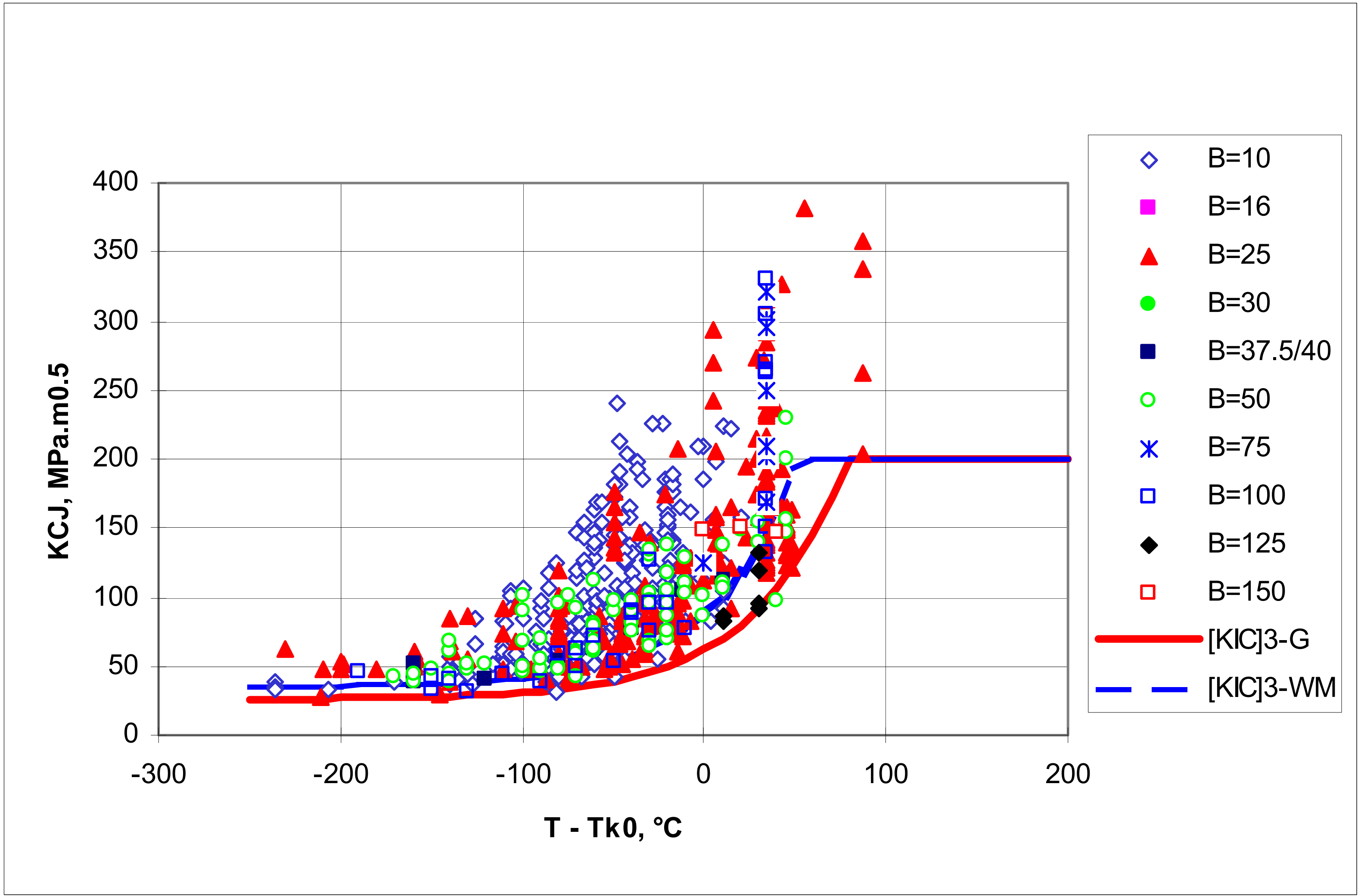
Original design fracture toughness curve applicable to base metals (PNAEG, VERLIFE) :

$$[K_{IC}]_3 = 26 + 36 \cdot \exp[(0.02\,(T - T_k)]$$

has been modified (RD-EO-0353-02, RD EO 0606 - 2005) as :

$$[K_{IC}]_3 = 23 + 48 \cdot \exp[(0.019\,(T - T_k)]$$

DESIGN FRACTURE TOUGHNESS CURVES



DESIGN FRACTURE TOUGHNESS CURVES

WWER (generalised curve) :

$$[K_{IC}\ (T-T_k)] = \min\{\ 26 + 36 \exp\ [0.020\ (T-T_k)];\ 200\}$$

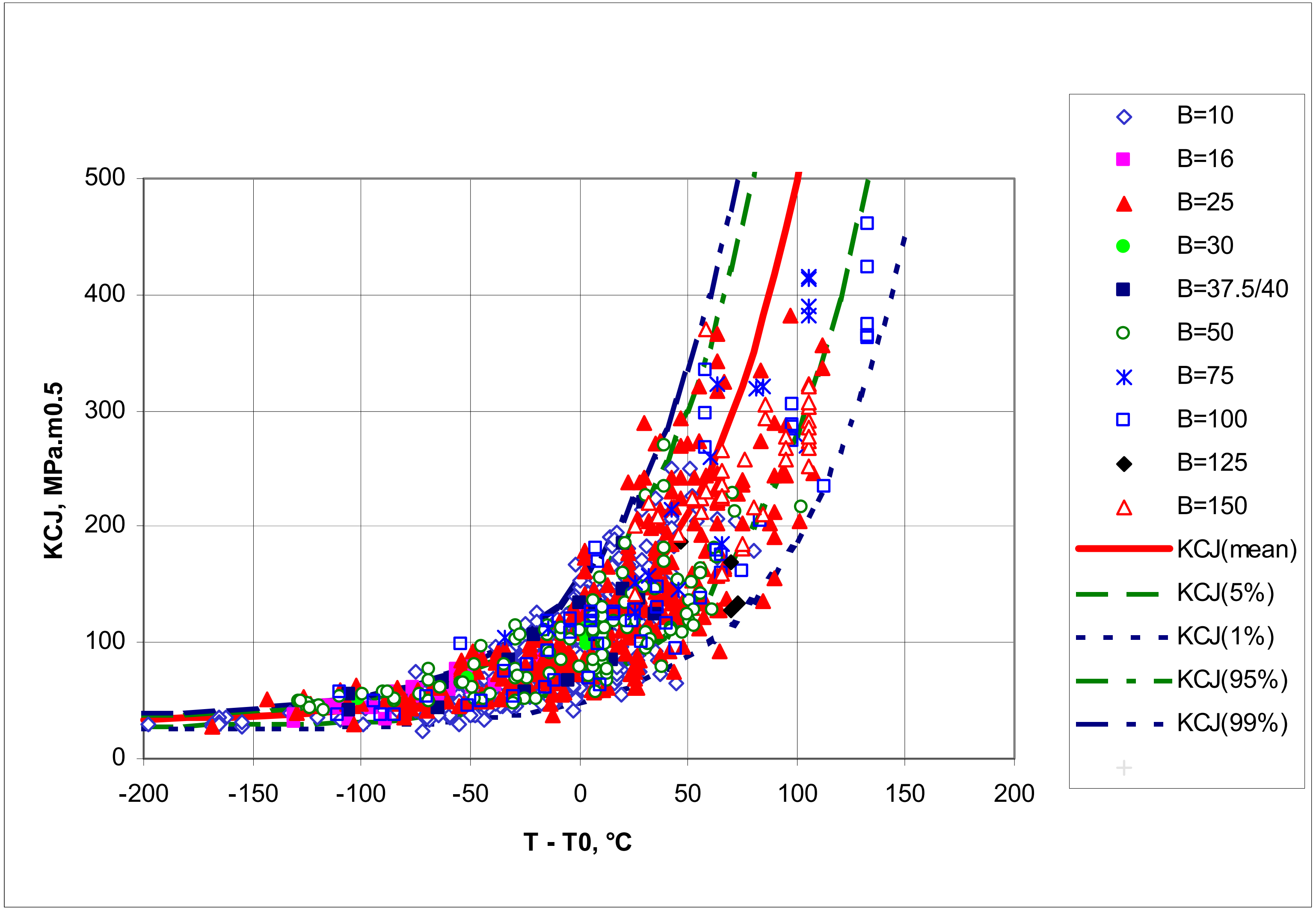
MASTER CURVE:

$$K_{JC(med)} = 30 + 70\ .\ \exp\ [\ 0.019\ (\ T - T_0\ )]$$

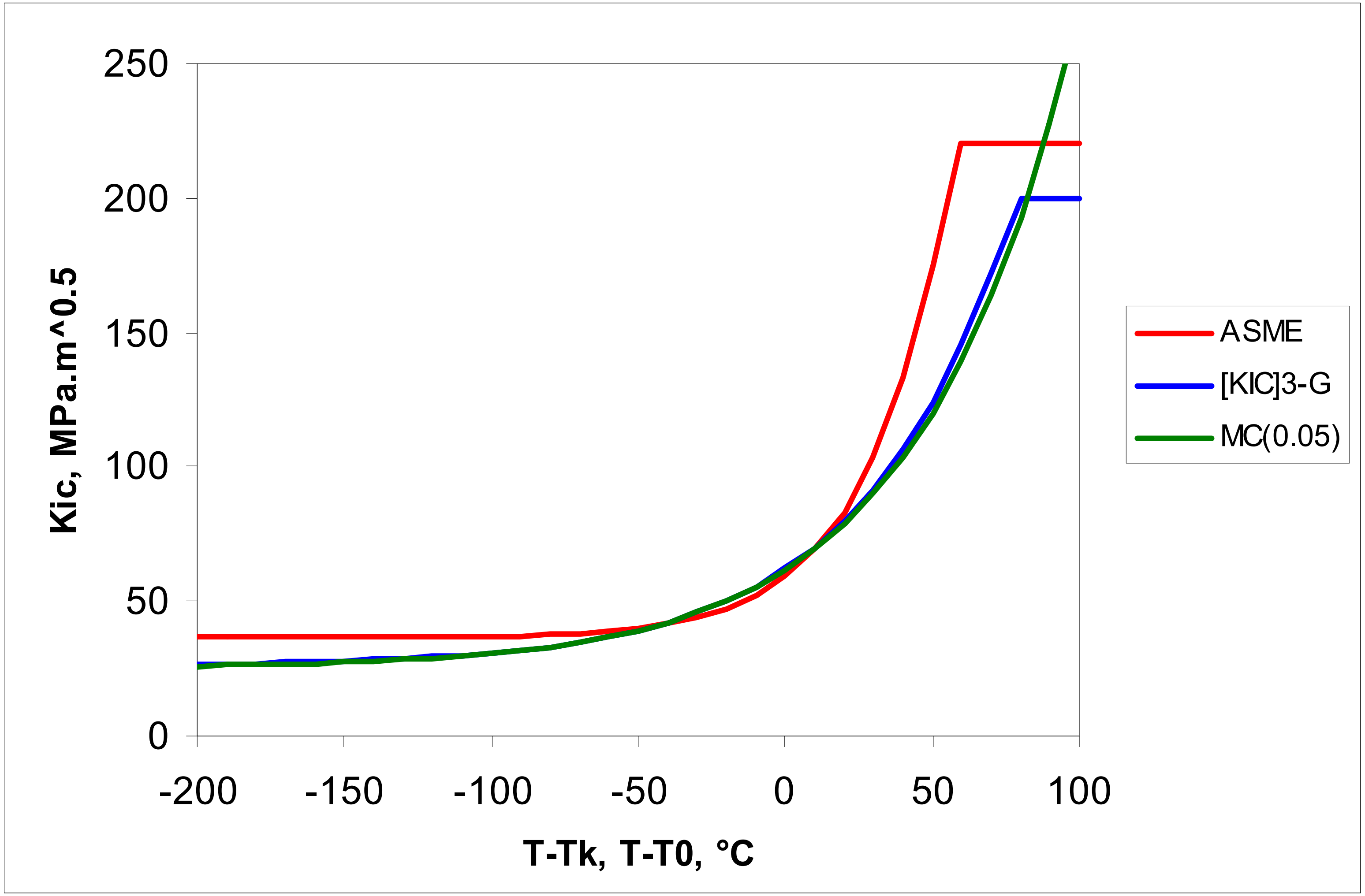
$$K_{JC(0.05)} = 25.2 + 36.6 \exp\ [0.019(T-T_0)]\}$$

$$K_{JC(0.95)} = 34.5 + 101.3 \exp\ [0.019(T-T_0)]\}$$

DESIGN FRACTURE TOUGHNESS CURVES

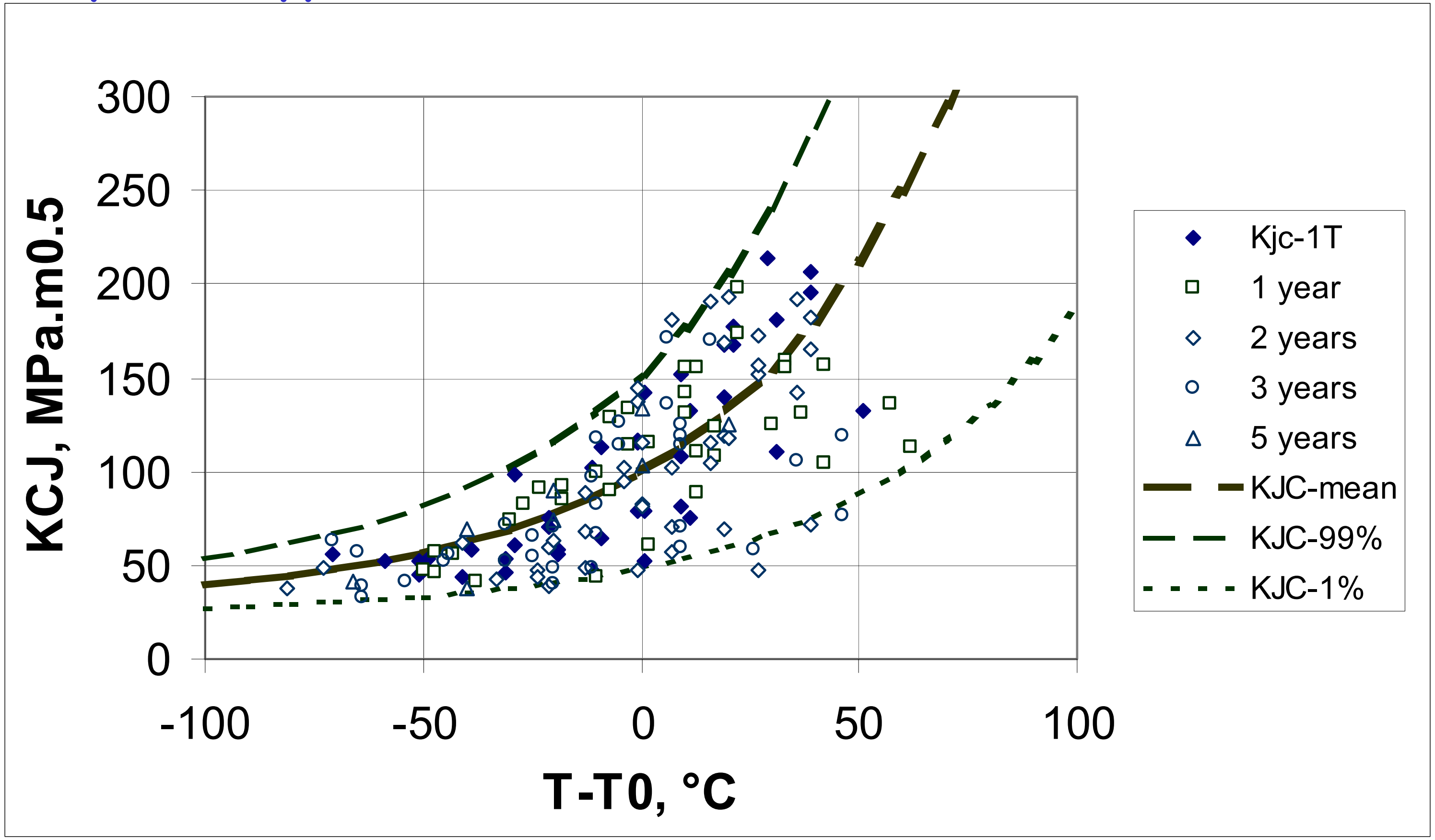


DESIGN FRACTURE TOUGHNESS CURVES



DESIGN FRACTURE TOUGHNESS CURVES

- Temperature dependence of WWER-440 RPV static fracture toughness of surveillance materials
  1 year = approx. $6 \times 10^{23} m^{-2}$ (E>0.5 MeV)



USE OF „MASTER CURVE"

- ACCORDING TO VERLIFE PROCEDURE:

Reference temperature T0

Reference temperature T0, increasing during operation, is determined experimentally from surveillance specimens irradiated to required neutron fluence. End-of-life design fluence should be taken as a basis for initial evaluations. Possible thermal and fatigue aging should be also taken into account.

USE OF „MASTER CURVE“

- Determination of reference temperature T_0 is performed using “Master curve“ approach using multi-temperature approach preferably to the single-temperature one.
- Reference temperature T_0 is defined from experimentally determined values of static fracture toughness, K_{JC}, adjusted to the thickness of 25 mm. Margin σ is added to cover the uncertainty in T_0 in accordance with Appendix III and for the assessment the value

$$RT_0 = T_0 + \sigma$$ is used.

USE OF „MASTER CURVE“

- Reference temperature, T_0, as determined in accordance with the standard ASTM E 1921-02 is increased by a margin, equal to a standard deviation $\Delta\sigma$ only for the tested condition, i.e. either initial or for a given degradation state. Reference temperature T_0 is defined from experimentally determined values of static fracture toughness, K_{JC}, adjusted to the thickness of 25 mm. Margin is added to cover the uncertainty in T_0 associated with using of only a few specimens to establish T_0. The standard deviation σ of the estimate of T_0 is given by:

  $$\sigma_1 = \beta / N^{0.5}, \ ^{o}C$$

  where N = total number of specimens used to establish the value of T_0,

  $$\beta = + 18 \ ^{o}C.$$

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USE OF „MASTER CURVE"

- To consider the scatter in the materials, another margin denoted in what follows δT_M should be applied. If this value is not available the application of the following values is suggested

  δT_M = 10°C for the base material,

  δT_M = 16°C for weld metals

USE OF „MASTER CURVE"

- The resulting margin is:

$$\sigma=(\sigma_1^{\,2}+T_M^{\,2})^{1/2}$$

Thus, reference temperature when used in integrity evaluation, RT_0, is defined as:

$$RT_0 = T_0 + \sigma$$

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USE OF „MASTER CURVE"

- *If the experimentally determined values of the initial critical temperature of brittleness T_{ko}* **from component Acceptance Tests are known (based on component Passport), they can be used only in the case that the following temperature margin δT_M will be added; the margin has to take into account the scatter of the values of mechanical properties in the semi-product; δT_M**

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USE OF „MASTER CURVE"

- δT_M is the mean quadratic deviation of T_{ko} determined for the given semi-product in the frame of Qualification Tests or in the frame of a set of identical semi-products established during production of the component by the identical technology. If this value is not available the application of the following values is suggested

  δT_M = 10°C for the base material,

  δT_M = 16°C for weld metals.

EVALUATION OF RADIATION DAMAGE

- Shift of the critical temperature of brittleness is determined from the formula

$$\Delta T_F = T_{kF} - T_{ki} \qquad (5)$$

where T_{kF} is a value of transition temperature for a fluence F,

T_{ki} is a value of transition temperature for initial conditions (unirradiated).

EVALUATION OF RADIATION DAMAGE

- In both cases, these temperatures are determined from similar sets of specimens (minimum 12) using similar test equipment and procedure. The difference in fluence between specimens of one set should be smaller than ±15 % of the mean value, and the difference in irradiation temperatures of individual specimens should be within a ± 10 °C. Finally, the mean value of irradiation temperature should be no higher than + 10 °C above the inner wall temperature of the reactor pressure vessel.

EVALUATION OF RADIATION DAMAGE

- Obtained experimental values of KV (impact notch energy) are evaluated using the following equation

$$KV = A + B\ th\ [(T\text{-}T0)/C] \qquad (6)$$

where A, B, C and T0 are constants derived by statistical evaluation. It is strongly recommended to set lower shelf energy at 3 J to avoid incorrect fitting when a small number of specimens are tested in the lower shelf energy temperature region.

EVALUATION OF RADIATION DAMAGE

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- Shift of the transition temperature is determined for the criterion

$$KV = 41\ J \qquad (7)$$

- This procedure results in valid values of ΔT_F only when the upper shelf energy, derived from the formula (6) - i.e., sum of (A+B), - is greater than 68 J.

EVALUATION OF RADIATION DAMAGE

- The results of determinations of the shift in the critical temperature of brittleness obtained at least for three different neutron fluences (the difference between the fluences has not be smaller than the value of the lowest fluence) are to be evaluated by the least squares method using the relationship:

$$\Delta T_F = A_F^{exp} \, . \, (F.10^{-22})^n \qquad (8)$$

where is the fluence of fast neutrons with the energy higher than 0.5 MeV, A_F^{exp} and *n* are empirical constants obtained by statistical evaluation.

EVALUATION OF RADIATION DAMAGE

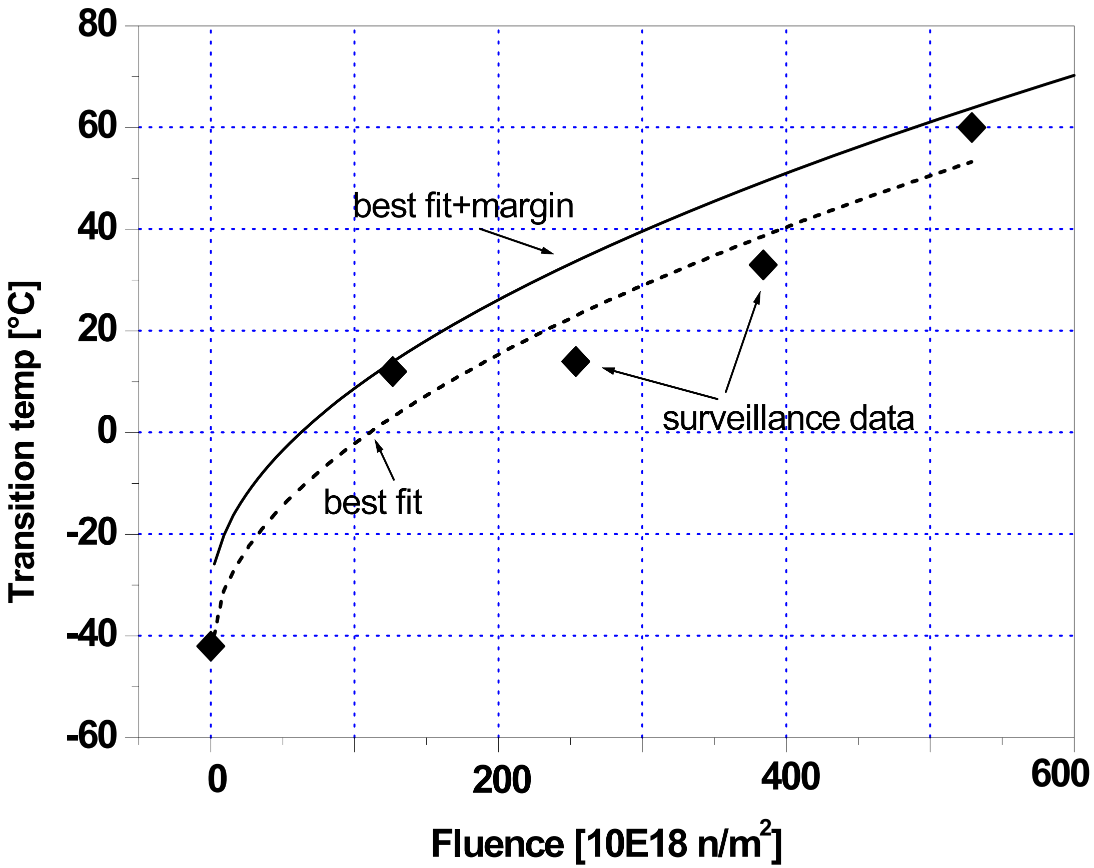
- Then, the mean trend curve should be vertically shifted upward by the value of δT_M. If any experimental point exceeds this adjusted trend curve, the curve should be shifted further until it bounds all data. This upper boundary of the shifts is to be used in assessment of RPV resistance against fast fracture

EVALUATION OF RADIATION DAMAGE

- It is not allowed to extrapolate shifts of the transient temperatures for the fluences higher than 20 % of the maximum fluence used for the experiment.

EVALUATION OF RADIATION DAMAGE

❑ EXAMPLE OF DATA FITTING-1



EVALUATION OF RADIATION DAMAGE

- *If there are insufficient surveillance test results:*
- **In a such a case, the coefficients of irradiation embrittlement have to be used in the following relationship for the pressurised reactor vessel materials in accordance to the formula (10):**
  - $\Delta T_F = A_F^{exp} . (F.10^{-22})^{1/3}$ **(10)**

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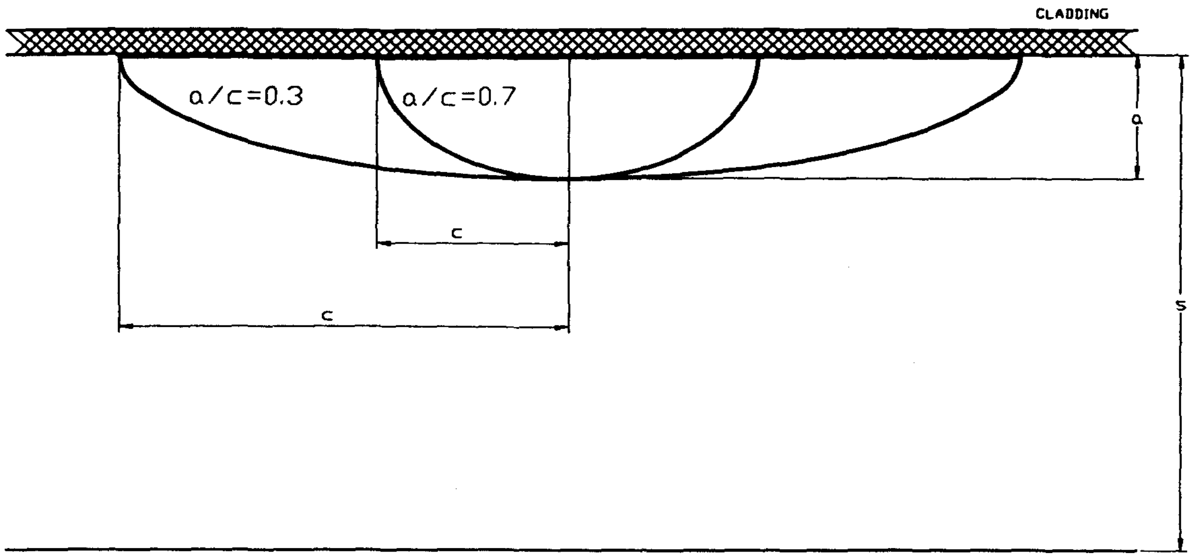
CRACK POSTULATION

❑ VERLIFE PROCEDURE:

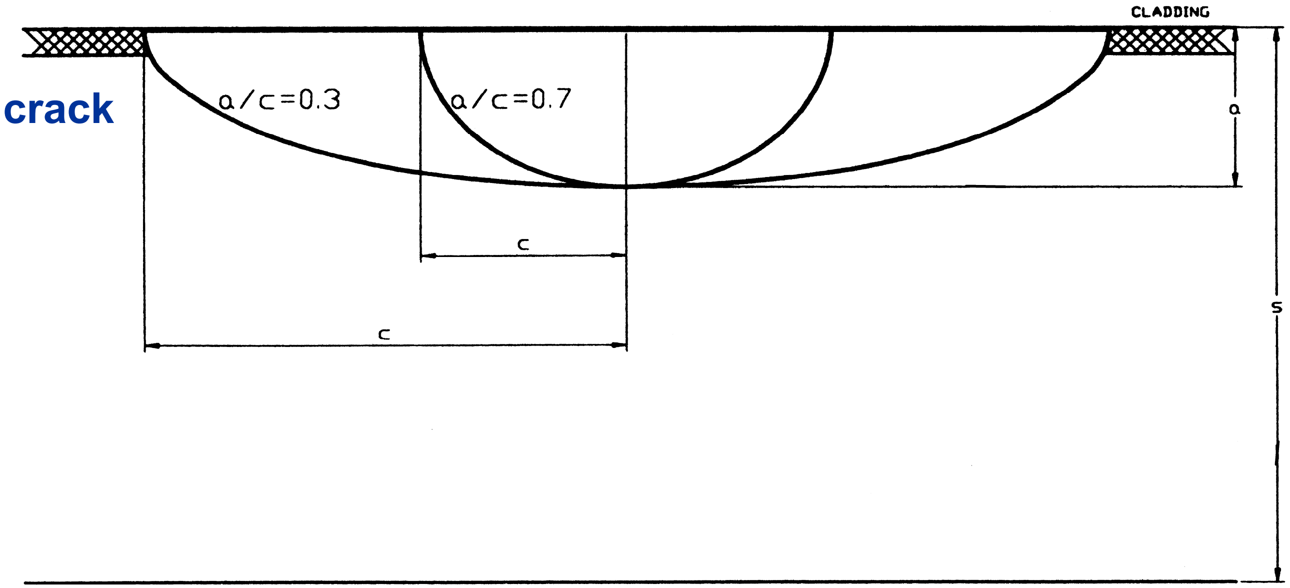
- ❑ Crack postulation is based on qualification of NDE for the RPV
- ❑ Orientation: both axial and circumferential cracks.
- ❑ Shape: semi-elliptical underclad or surface cracks.
- ❑ Depth: in the case when qualified non-destructive testing (NDT) is used, the depth is defined on the basis of the qualification criteria
  - recommended value *acalc* = *s*/10, (*s* is wall thickness)
  - i.e. 15 mm for WWER 440
  - 20 mm for WWER 1000.
  - without qualification of NDT: *acalc* = *s*/4,
- ❑ Aspect ratio: *a*/*c* = 0.3 and *a*/*c* = 0.7.
- ❑ Assessed points on the crack front: at least near interface points and the deepest point (the whole crack front assessment is recommended).

CRACK POSTULATION

Underclad crack

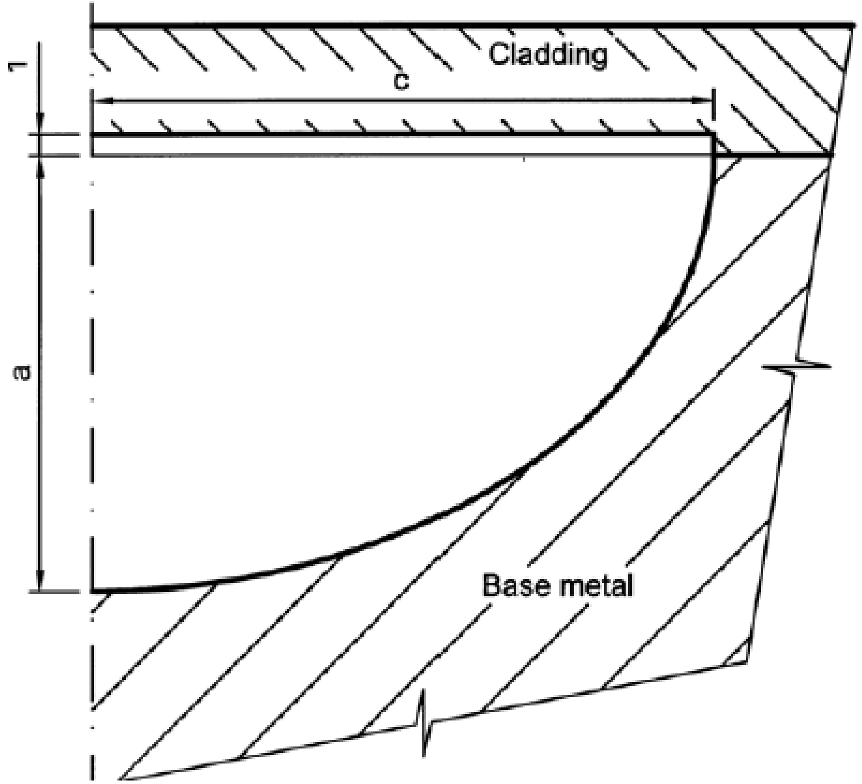


Surface breaking crack



CRACK POSTULATION

- Undreclad crack may be postulated for cladded RPV, provided that integrity of cladding is assured by qualified non-destructive inspections.
- Assessment of effect of cladding is based on the use of its J-R curve (in the case of multi-layer cladding, J-R curve for the 1st layer).
- The postulated underclad crack is conservatively defined as partially penetrating 1 mm into the cladding.



CRACK POSTULATION

- In this case, the integrity of cladding above the postulated defect during the whole PTS regime has to be verified.
- J-values for all time steps of the regime shall be calculated (it is sufficient to calculate J-values only for the middle point of crack front in cladding).
- These J-values have to be (for all assessed time steps) smaller than the end-of-life values of J-R curve corresponding to 1 mm crack extension (i.e. J_{1mm} values).
- The J_{1mm} values are specified as follows:

  a) If no RPV specific data are available, generic values of J_{1mm} are:

  100 kJ/m² for WWER 440 RPV

  150 kJ/m² for WWER 1000 RPV.

  b) If component specific data are available, then experimentally determined J_{1mm} divided by safety factor 2 shall be used.

CRACK POSTULATION

❑RUSSIA PROCEDURE MRKR:

- ❑ **Methodology of Determination of the Residual Lifetime of the Reactor Pressure Vessels of WWER Reactors During Operation, MRKR-SChR-2004"** (in Russian)
- ❑ **Crack postulation is based on results from NDE for the RPV during manufacturing, only**
- ❑ **Shape: semi-elliptical underclad or surface cracks.**
- ❑ **Depth: no requirements for qualified non-destructive testing (NDT)**
  - **recommended value *acalc = 0.07 s*** **(*s* is wall thickness)**
  - **i.e. 10 mm for WWER 440**
  - **14 mm for WWER 1000.**
- ❑ **Aspect ratio: *a/c* = 0.3 and *a/c* = 0.7.**

COMPARISON OF APPROACHES

	China		Czech Rep.	Finland	France	Germany	Hungary	Korea	Slovakia	Russia
Reactor Type	**PWR**	**VVER**[1]	**VVER**	**VVER and PWR**	**PWR**	**PWR**	**VVER**	**PWR**	**VVER**	**VVER**
Codes/ Approaches	**ASME XI**	**PNAE G-7-002-86/ VERLIFE**	**VERLIFE**	**ASME III, XI, VERLIFE**	**RSE-M**	**KTA**	**VERLIFE**	**ASME XI**	**VERLIFE**	**MRKR-SKhR-2004**

[1] Chinese VVER: calculations were performed for design stage in 1998-1999

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COMPARISON OF APPROACHES

	China		Czech Rep.	Finland	France	Germany	Hungary	Korea	Slovakia	Russia
Critical Transients										
Transients	SB-LOCA LB-LOCA Overcooling with repressurization based on PRA	SB-LOCA	LB LOCA, PRZ SV opening + reclosure	Large LOCA Safety valve opening and reclosure Cold pressurization External cooling	LB-LOCA & SB-LOCA SLB-SSLB	SB-LOCA and critical transient selected by fracture mechanics	LB LOCA SLB Overcooling with repressurization	SGTR SBLOCA MSLB	Case to case, mainly transients with pressurization under low temperature as Small LOCA, Primary to secondary leakage	VVER-1000: Primary Small LOCA, Primary to Secondary Leakage VVER-440: Primary Small LOCA, Secondary Leakage

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COMPARISON OF APPROACHES

	China		Czech Rep.	Finland	France	Germany	Hungary	Korea	Slovakia	Russia
Thermo-Hydraulic Computation										
Tools for global system	RELAP 5	TRAP	RELAP 5	APROS, RELAP5	Cathare	S-RELAP5 Version V311 PTS	RELAP5 ATHLET	RETRAN-3D RELAP5/MOD3.2	RELAP4	TRAP code
Plumes and mixing (Y/N)	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Tools for mixing analysis	No	Engineering approach based on experimental results	REMIX/NEWMIX, CATHARE	REMIX	SATURNE SYRTHES	KWU-MIX	REMIX	PHOENICS	EBOMIX	OKBMIX code

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COMPARISON OF APPROACHES

	China		Czech Rep.	Finland	France	Germany	Hungary	Korea	Slovakia	Russia
Fluence										
Measurement via monitoring (Y(position)/N)	Yes		Y, surveillance capsules, outer surface	Y (samples outside RPV, max fluence)	Yes	Yes	Yes (surveillance capsules)	Yes	Yes	Yes (surveillance capsules, templates, outer surface)
Calculation	Yes	Yes	Yes	Yes	Yes	Y 3D	Yes	Yes	recalculation based on measured values	Yes
Attenuation through the thickness (Y/N)	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes

COMPARISON OF APPROACHES

	China		Czech Rep.	Finland	France	Germany	Hungary	Korea	Slovakia	Russia
Vessel Temperature and Stress Evaluation										
FE (tools) or analytical	MSC.MA RC	MSC.MARC	FE, SYSTUS	FE (FLUENT, ABAQUS)	FE (ASTER, CUVE1D, CASTEM, SYSTUS analytical	FE	MSC.MARC	FE (ABAQUS, ANSYS)	FE - ADINA	FE
Elastic or elastic/plastic	Both	Elastic	Elastic-plastic	Elastic-plastic	Elastic-plastic FE or elastic + plastic correction	Elastic-plastic	Elastic, Elastic-plastic	Elastic, Elastic-plastic	Elastic-plastic	Elastic-plastic
Safety factor on loading	No	No	No	Level A Service limits 2 (primary), 1 (secondary)	Level A: 2 Level C: 1.6 Level D: 1.2	1	No	No	No	Yes
Weld residual stress (Y/N)	Yes	Yes	Yes	Yes	In clad: Yes In weld: No	Yes	Yes	Yes	Yes	Yes

COMPARISON OF APPROACHES

	China		Czech Rep.	Finland	France	Germany	Hungary	Korea	Slovakia	Russia
Crack Driving Force										
Postulated surface defects (depth and aspect ratio, shape 1 or 2)	Shape 2 Depth=0.1t or based on NDE a/c=1/3	Depth up to 0.25t a/c=2/3 Surface semi elliptical crack in the base or weld metal	No	Shape 1 15 mm, aspect ratio 1 (Loviisa)	design: a= 20 mm a/c=0.3	No	Depth up to 0.1t; a/c=1/3 Shape 1 Inelastic	0.1t or based on NDE a/c=1/3 shape 2	a=0.1, a/c=0.3, 0.7, shape 2	0,07t+cladding thickness, shape 2, a/c=1/3[1]
Postulated sub-surface defects (depth and aspect ratio)	Depth=15mm or based on NDE a/c=1/3	No	a = 0.1*s, a/c = 0.3 and 0.7	No	Operation: a = 6 mm, 2c=60 mm	Depth=NDE x2 (10 mm) Ratio a/2c=1/6	Depth up to 0.1t; a/c=1/3 Shape 1 Inelastic	N0	a=0.1, a/c=0.3, 0.7, shape 2	0,07t, a/c=1/3
Cladding considered (Y/N)	Yes	Cladding considered only in temperatures and stresses calculations	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
K estimation method (handbook, plasticity correction, FE)	FE, ASME XI with plasticity correction	Analytical formula, no plasticity correction	FE, G-theta method	FE	Elastic un-cracked model Handbook + plasticity correction	FE	Handbook for elastic; FE for elasto-plastic	FE, Handbook	FE	FE, Handbook
Safety factor on K_I		No	No	No	No (on load)	No	No	No	No	1.1

[1] Russian approach: postulated defect is selected according to the size of a realistic manufacturing defect i.e. which could probably exist (with appropriate margins)

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COMPARISON OF APPROACHES

	China		Czech Rep.	Finland	France	Germany	Hungary	Korea	Slovakia	Russia
Material Fracture Resistance										
Crack initiation parameter (RT_{NDT}, T_k, To)	RT_{NDT} T_o	T_k	T_0 or T_k	To ,(T_k)	RT_{NDT}	RT_{NDT}	T_0 or T_k	RT_{NDT}, T_o	T_k	T_k
Crack Arrest (Y/N)	If required	No	Not until now	Yes	No	Yes	Not utilised	Yes	No	No
Shift formula for radiation embrittlement (code, surveillance)	R.G 1.99 and surveillance test	Code (PNAE G-7-002-86)	design – code operation – surveillance results	Direct measurement on toughness of irradiated specimens and Russian code	- CVN shift - from all the surveillance programs of 58 plants	Surveillance	Surveillance results	RG1.99, surveillance	surveillance	Code+Surveillance
Safety factors	$2^{0.5}$	No	On predicted T_0 or T_k	10°C	lower bound	1	On predicted T_k or T_o	$2^{0.5}$	according to VERLIFE	Yes

COMPARISON OF APPROACHES

	China		Czech Rep.	Finland	France	Germany	Hungary	Korea	Slovakia	Russia
Integrity Evaluation Criteria										
Cleavage (Y/N)	Yes	Yes	Yes	Yes	Yes + ductile with thermal ageing considering surface content	Yes	Yes	Yes	Yes	Yes

COMPARISON OF APPROACHES

	China		Czech Rep.	Finland	France	Germany	Hungary	Korea	Slovakia	Russia
Integrity Evaluation Criteria										
Cleavage (Y/N)	Yes	Yes	Yes	Yes	Yes + ductile with thermal ageing considering surface content	Yes	Yes	Yes	Yes	Yes
Ductile in cladding (Y/N)	No	No	Not up to now (yes in future)	No	Yes	Yes	Not up to now (yes in future)	No	Yes	Yes
Crack arrest (Y/N)	Yes	No	Not until now	Yes	No	Yes	Not until now	Yes	No	No
Crack length correction (Y/N)	No	No	Y for T_0 approach only	Yes	Yes, reference toughness curve length = 100 mm	No	No	No	No	Yes
Fatigue crack growth correction (Y/N)	Yes	No	N for postulated defect Y for real defect (from ISI) assessment	No	Yes (but negligible in vessel wall)	No	No	No	No	Yes
WPS (Y/N)	No	No	Yes (monotonical unloading only)	Yes (Large LOCA, external)	No	Yes	Yes	No	Yes	Yes
Shallow crack effect loss (Y/N)	No	No	No	No	No	No	No	No	No	Yes
Biaxial Effects (Y/N)	No	No	No	No	No	No	No	No	No	Yes

COMPARISON OF APPROACHES

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	China		Czech Rep.	Finland	France	Germany	Hungary	Korea	Slovakia	Russia
Nozzles										
Nozzle Considered (Y/N)	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes
Postulated crack, size, shape	Depth=(0 .025-0.1)t Elliptical Only performe d during design	Depth up to 0.25t a/c=2/3 Surface semi elliptical crack in the base or weld metal		Based on NDE; sub-surface (10x18 mm)	- circular - 20 mm depth	Inlet: nozzle corner,6 o'clock ,straight crack front, size : NDEx2 (10mm) Outlet nozzle: cylindrical part, 6 o'clock, semi-elliptical, a/2c=1/6, size NDEx2 (10mm)	Surface and underclad flaws in lower nozzle, a=0.1t, a/c = 1/3		surface and underclad cracks in radius, a=0.1-0.25, a/c=1	Initial depth 0,07t, fatigue crack growth is considered, a/c=1/3

CONCLUSIONS

- PWR AND VVER EVALUATION PROCEDURES FOR RPV INTEGRITY ARE BASED ON SIMILAR PRINCIPLES BUT THEY DIFFER IN MANY ASPECTS
- DIFFERENCES ARE MOSTLY CONNECTED WITH THE USE OF DIFFERENT MATERIALS AND DESIGN CODES
- VERLIFE PROCEDURE FOR VVER INTEGRITY AND LIFETIME EVALUATION TRIES TO HARMONIZE OLD VVER APPROACH WITH PWR ONE
- VERLIFE PROCEDURE IS NOW BEING UPGRADED, UPDATING AND EXTENDED (WITH PARTICIPATION OF EXPERTS FROM ALL VVER COUNTRIES AS WELL AS OTHER PWRs) AS AN IAEA GUIDELINES

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Pressurised Thermal Shock in Nuclear Power Plants: Good Practices for Assessment

Handbook on Deterministic Evaluation for the Integrity of Reactor Pressure Vessel

Report prepared within the framework of the IAEA programme on engineering support for design, operation, maintenance, and plant life management for safe long term operation

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Thank you for your attention

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